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Combustion Modification NOx Controls for Utility Boilers. Volume III: Residual Oil Wall-Fired Unit Field Test

Acurex Corp.
Mountain View, CA

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

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COMBUSTION MODIFICATION NO_x CONTROLS FOR UTILITY BOILERS

Volume III. Residual Oil Wall-fired Unit Field Test

Prepared for

Office of Air Quality Planning and Standards

Prepared by

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

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16. ABSTRACT
The report gives methods and results of an environmental assessment test program at Pacific Gas and Electric's Moss Landing Power Plant, Unit 6. The aim of the program was to measure changes in emissions as a result of applying NOx controls. Emissions of trace elements, organic materials, sulfur species, particulate matter, CO2, O2, NOx, and CO were measured. These emissions, under as-designed and controlled (for NOx) operating conditions, were compared. Source operating data were also analyzed so that changes in operating parameters and efficiency could be assessed. Unit 6 is a 2.3 Gg/hr (5.1 million lb/hr) steam, oil- and gas-fired supercritical electric utility boiler (740-MW generator output). This horizontally opposed, once-through, radiant, reheat, pressurized furnace type steam generator has been in service since 1967. The fuel used was a blend of residual and crude oil. Two degrees of NOx control were tested: the highest level, corresponding to present boiler operation, consisted of burners-out-of-service and flue gas recirculation (FGR) to the windbox; and the other, representing an intermediate degree of control, consisted of only FGR to the windbox. Both reduced NOx from baseline levels by 43 and 26%, respectively. Boiler efficiency was not affected by low-NOx operation. Little change in other emissions was caused by these NOx controls.

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July 1981

COMBUSTION MODIFICATION NO_x CONTROLS FOR UTILITY BOILERS
VOLUME III: RESIDUAL OIL WALL-FIRED UNIT FIELD TEST

by

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ABSTRACT

This test report describes the methods and results of an environmental assessment test program conducted at Pacific Gas and Electric's Moss Landing Power Plant, Unit 6. The purpose of the test program was to measure changes in emissions as a result of applying NO_x controls. Emissions of trace elements, organic materials, sulfur species, particulate matter CO_2, O_2, NO_x, and CO, were measured. Comparisons of these emissions under "as-designed" operating conditions and controlled (for NO_x) operating conditions were then made. Source operating data were also analyzed so that changes in operating parameters and efficiency could be assessed.

Moss Landing Unit 6 is a 2.3 Gg steam per hour (5.1×10^6 lbs. steam per hour) oil- and gas-fired supercritical electric utility boiler (740 MW generator output). This horizontally opposed, once-through, radiant, reheat, pressurized furnace type steam generator has been in service since 1967.

Two degrees of NO_x control were tested on this boiler. The highest level, which corresponds to present boiler operation, consisted of burners-out-of-service and flue gas recirculation to the windbox. The second level of NO_x control representing an intermediate degree of control, consisted of only flue gas recirculation to the windbox. These measures achieved NO_x reductions from baseline levels of 43 and 26 percent respectively. Boiler efficiency was not affected by low NO_x operation.

The test program concludes that applying combustion modification NO_x controls did not affect particulate or sulfur species emissions. Very little change occurred in trace element partitioning from the reduced NO_x firing modes. Organic emissions were reduced slightly by NO_x controls.

Cytotoxicity and mutagenicity (Ames) tests were done on the first level of NO_x control flue gas organic sample. It was found to possess nondetectable toxicity and did not cause mutagenic activity in the Ames test. However, the sample was found to be moderately toxic to WI-38 cells.

TABLE OF CONTENTS

Section		Page
1	INTRODUCTION.	1-1
2	TEST SITE DESCRIPTION	2-1
3	TEST PLAN	3-1
	3.1 Unit Operation	3-1
	3.2 Sampling and Analysis.	3-2
	3.2.1 Sampling	3-2
	3.2.2 Analysis	3-6
4	TEST PROGRAM RESULTS.	4-1
	4.1 Unit Operations	4-1
	4.2 Flue Gas Composition	4-2
	4.3 Particulate Emissions.	4-4
	4.4 Fuel and Flue Gas Trace Element Characterization and Emissions	4-6
	4.5 Sulfur Species Emissions	4-8
	4.6 Organic Analyses	4-8
	4.6.1 C_1 to C_6 Flue Gas Hydrocarbon Analyses	4-11
	4.6.2 Total Chromatographable Organics (TCO) and Gravimetric Analyses of Organic Extracts	4-12
	4.6.3 Infrared and Gas Chromatographic Mass Spectral Analysis of Total Extracts	4-12
	4.6.4 Column Chromatography.	4-16
	4.6.5 Infrared and Mass Spectral (GC/MS and LRMS) Analyses of Fractions from Column Chromatography	4-16
	4.6.6 Summary of Organic Analyses.	4-19
	4.6.7 Bioassays.	4-19
5	SUMMARY	5-1

LIST OF TABLES

Table		Page
1-1	NO_x EA Field Test Program.	1-2
3-1	Flue Gas Continuous Monitoring	3-4
3-2	Data and Samples Collected	3-8
3-3	Trace Elements Analyzed for In Moss Landing Samples. .	3-9
3-4	Key Operating Data Collected at Moss Landing, Unit 6 .	3-10
4-1	Furnace Operating Conditions	4-1
4-2	Fuel Analyses.	4-3
4-3	Boiler Efficiency.	4-3
4-4	Flue Gas Composition	4-4
4-5	EPA Method 5 Particulate Concentration	4-5
4-6	SASS Particulate Concentration	4-5
4-7	Vapor-Solid Partitioning	4-7
4-8	Sulfur Species Analysis.	4-10
4-9	Sulfur Species Balance	4-11
4-10	Flue Gas Hydrocarbon Analysis for Moss Landing, CA . .	4-12
4-11	Results of Gravimetric and TCO Analysis of XAD-2 Extract.	4-13
4-12	Summary of Absorbances Found in Samples, But Not In Method Blank for XAD-2.	4-14
4-13	Compounds for Which GC/MS Analysis Was Performed in the Moss Landing XAD-2 Extracts	4-15
4-14	Organics Detected in Moss Landing XAD-2 Extracts . . .	4-16
4-15	Gravimetric and TCO Results of Column Chromatography of the Baseline XAD-2 Sample	4-17
4-16	Infrared Analysis of Column Chromatography Fractions .	4-18

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SECTION 1

INTRODUCTION

This report is part of a series of test reports resulting from the experimental testing task of the "Environmental Assessment of Stationary Source NO_x Control Technologies" (NO_x EA) program being performed under EPA Contract 68-02-2160. The NO_x EA is a 3-year program to: (1) identify the multimedia environmental impact of stationary combustion sources and combustion modification NO_x controls; and (2) identify the most cost-effective, environmentally sound NO_x controls for attaining and maintaining current and projected NO_2 air quality standards to the year 2000.

During the first year of the NO_x EA, a preliminary environmental assessment concluded that emissions and operating data needed to perform adequate process engineering and environmental assessment activities were severely lacking in several key areas. Most noteworthy was the virtual absence of data on noncriteria flue gas emissions and liquid and solid effluents (Reference 1). In response to these identified data needs, NO_x EA field test programs were initiated. Source selection was based on a source/control priority listing developed in the preliminary environmental assessment. These test programs were designed to provide information on changes in emissions and operation due to NO_x controls. The NO_x EA field test program is outlined in Table 1-1.

The test program documented in this report was conducted on the Pacific Gas and Electric's Moss Landing Power Plant, Unit 6. Moss Landing, Unit 6 was selected because it is one of the most stringently controlled (for NO_x) oil-fired boilers in the United States. It is an oil- and gas-fired electric utility boiler producing 2.3 Gg steam per hour (5.1×10^6 lb steam per hour). This unit is a typical large oil- and

TABLE 1-1. NO_x EA FIELD TEST PROGRAM

Source Category	Description	Test Points (Unit Operation)	Sampling Protocol	Test Collaborator	Status
Coal-fired Utility Boiler	Kingston #6; 180 MW tangential; twin furnace, 12 burners/furnace, 3 elevations; cyclone, 2 ESP's for particulate control	Baseline Biased Firing (2) BOOS (2)	Continuous NO_x, SO_2, CO, CO_2, O_2 Inlet to 1st ESP: -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Outlet of 1st ESP: -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Bottom ash Hopper ash (1st ESP, cyclone) Fuel Operating data	TVA	Complete, August 1977
Coal-fired Utility Boiler	Crist #7, 500 MW opposed wall fired; 24 burners, 3 elevations; ESP for particulate control	Baseline BOOS (2)	Continuous NO_x, CO CO_2, O_2 ESP inlet -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) ESP outlet -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Bottom ash ESP hopper ash Fuel Operating data Bioassay	Exxon	Complete, June 1978
Oil-fired Utility Boiler	Moss Landing #6, 740 MW opposed wall fired; 48 burners, 6 elevations	Baseline FGR FGR + OFA	Continuous NO_x, CO, CO_2, O_2 Flue gas -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Fuel Operating data Bioassay	New test start	Complete, September 1978

EE-073

TABLE 1-1. Continued

Source Category	Description	Test Points (Unit Operation)	Sampling Protocol	Test Collaborator	Status
Coal-fired Industrial Boiler	Traveling grate spreader stoker, 38 kg/s (300,000 lb/hr); ESP for particulate control; wet scrubber for SO_x control	Baseline LEA + high OFA	Continuous NO_x, CO, CO_2, O_2 Boiler exit: -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) ESP outlet -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) Bottom ash Cyclone hopper ash Fuel Operating data	KVB	Complete, October 1977
Coal-fired Industrial Boiler	Traveling grate spreader stoker, 25 kg/s (200,000 lb/hr) ESP for particulate control	Baseline LEA + High OFA	Continuous NO_x, CO, CO_2, O_2 Boiler exit: -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) ESP Outlet -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) Bottom ash ESP hopper ash Fuel Operating data Bioassay	KVB	Complete, February 1978
Oil-fired Gas Turbine	T.H. Wharton Station, 60 MW GE MS 7001 C machine	Baseline water injection to meet proposed NSPS	Continuous NO_x, CO CO_2, O_2 Exhaust gas -- SASS -- Method 5 -- Method 8 Fuel Water Operating data	General Electric	Complete, April 1978

EE-073

TABLE 1-1. Concluded

Source Category	Description	Test Points (Unit Operation)	Sampling Protocol	Test Collaborator	Status
Oil-fired Residential Heating Unit	Blue Ray low NO_x furnace, Medford, New York	Continuous Cycling	Continuous NO_x, CO CO_2, O_2 Flue gas -- SASS -- Method 5 -- Method 8 Fuel	New test start with EPA/IERL-RTP	Complete, November 1977

EE-073

gas-fired utility boiler. This unit was made available for testing in the NO_x EA field test program through the cooperation of the Pacific Gas and Electric Company.

The NO_x EA field test program at Moss Landing consisted of a baseline test and tests under two modes of low NO_x operation using oil fuel. The first mode of low NO_x operation was combined Burners-Out-Of Service (BOOS) and Flue Gas Recirculation (FGR) to the windbox. The second mode was flue gas recirculation through the burners only. The combination of BOOS and FGR is referred to as the BOOS/FGR test. The results of the test program will be used in both process analysis and source assessment modeling, conducted as part of the Environmental Assessment and Process Engineering tasks of the NO_x EA.

SECTION 2
TEST SITE DESCRIPTION

The Moss Landing Power Plant is located on a 383-acre site along the Monterey Bay waterfront at Moss Landing, California. Combined electric generation capacity of the seven units at Moss Landing is 2060 MW. Units 1, 2, and 3 began operation in 1950. Units 4 and 5 were added in 1952. Unit 6 was completed in 1967, and Unit 7 in 1968. Units 6 and 7 are both supercritical units rated at 739 MW electrical output each. Moss Landing Unit 6 was the unit tested.

Moss Landing Unit 6 is a horizontally opposed oil- and gas-fired once-through, radiant, reheat, pressurized furnace type steam generator, supplied by the Babcock and Wilcox Company. Capacity of the boiler is 2.3 Gg steam per hour (5.1×10^6 lb steam per hour) at 26.5 MPa (3845 PSIA) and 815 K ($1005^{\circ}F$) with a single reheat to 815 K ($1005^{\circ}F$). Steam temperature is controlled by superheat-reheat flue gas proportioning dampers, flue gas recirculation, and spray attemperation. Fuel is supplied to the furnace through 48 burners. Burner arrangement is six rows of four burners per the front and rear furnace walls.

The flue gas exits through two ducts to a stack 152 m (500 ft) tall, 20 m (66 ft) diameter at the base and 6 m (20 ft) diameter at the top. Figure 2-1 shows the steam-turbine cycle for the Moss Landing unit. Figure 2-2 shows a cross section of the boiler.

This unit is presently under local NO_x control regulations using both burners out of service and flue gas recirculation through the burners, as retrofit controls, to achieve compliance. Low NO_x emission operations began in 1971. Compliance levels for this boiler are 225 ppm NO_x at 3 percent O_2 while burning oil fuel. During the test program, it was necessary to "remove" the NO_x controls, under a variance granted by the Monterey Bay Unified Air Pollution Control District, for the baseline and flue gas recirculation tests.

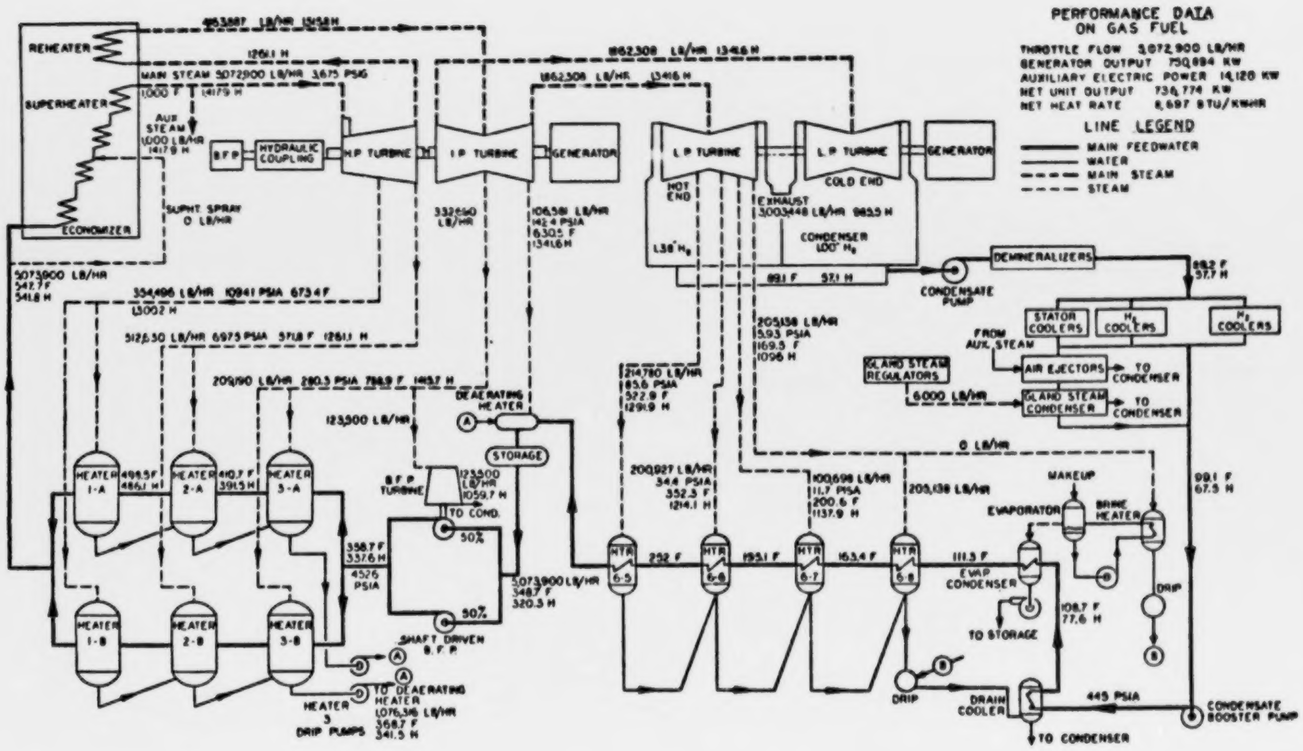

PERFORMANCE DATA
ON GAS FUEL
THROTTLE FLOW 3,072,900 LB/HR
GENERATOR OUTPUT 750,894 KW
AUXILIARY ELECTRIC POWER 14,120 KW
NET UNIT OUTPUT 736,774 KW
NET HEAT RATE 8,697 BTU/KWHR
LINE LEGEND
MAIN FEEDWATER
WATER
MAIN STEAM
STEAM
REHEATER
SUPERHEATER
ECONOMIZER
4953887 LB/HR 1515.8 H
1261.1 H
MAIN STEAM 3072900 LB/HR 3,675 PSIG
1,000 F 1417.9 H
AUX STEAM 1,000 LB/HR 1417.9 H
SUPHT. SPRAY 0 LB/HR
B.F.P.
HYDRAULIC COUPLING
H.P. TURBINE
I.P. TURBINE
GENERATOR
L.P. TURBINE
HOT END
L.P. TURBINE
COLD END
GENERATOR
1862,308 LB/HR 1341.6 H
1862,308 LB/HR 1341.6 H
332,650 LB/HR
106,581 LB/HR
142.4 PSIA
630.5 F
1341.6 H
EXHAUST
3003,448 LB/HR 983.5 H
CONDENSER
1.00" Hg
1.38" Hg
89.1 F
57.1 H
CONDENSATE PUMP
DEMINERALIZERS
89.2 F
57.7 H
STATOR COOLERS
H2 COOLERS
H2 COOLERS
FROM AUX. STEAM
AIR EJECTORS
TO CONDENSER
GLAND STEAM REGULATORS
6000 LB/HR
GLAND STEAM CONDENSER
TO CONDENSER
3073900 LB/HR
547.7 F
541.8 H
354,496 LB/HR 1094.1 PSIA 673.4 F
1300.2 H
512,630 LB/HR 697.5 PSIA 571.8 F 1261.1 H
209,190 LB/HR 280.3 PSIA 788.9 F 1415.7 H
123,300 LB/HR
DEAERATING HEATER
A
STORAGE
B.F.P. TURBINE
123,300 LB/HR
1059.7 H
TO COND.
50%
50%
SHAFT DRIVEN B.F.P.
HEATER 1-A
499.5 F
486.1 H
HEATER 2-A
410.7 F
391.5 H
HEATER 3-A
HEATER 1-B
HEATER 2-B
HEATER 3-B
358.7 F
337.6 H
4526 PSIA
3,073,900 LB/HR
348.7 F
320.3 H
A
A
TO DEAERATING HEATER
1,076,316 LB/HR
368.7 F
341.5 H
HEATER 3
DRIP PUMPS
214,780 LB/HR
85.6 PSIA
572.9 F
1291.9 H
205,138 LB/HR
5.93 PSIA
169.5 F
1096 H
200,927 LB/HR
34.4 PSIA
352.3 F
1214.1 H
100,698 LB/HR
11.7 PSIA
200.6 F
1137.9 H
205,138 LB/HR
0 LB/HR
HTR 6-5
252 F
HTR 6-6
195.1 F
HTR 6-7
163.4 F
HTR 6-8
111.3 F
EVAP CONDENSER
TO STORAGE
EVAPORATOR
MAKEUP
BRINE HEATER
DRIP
B
B
DRIP
108.7 F
77.6 H
DRAIN COOLER
TO CONDENSER
445 PSIA
99.1 F
67.5 H
CONDENSATE BOOSTER PUMP

Figure 2-1. Steam cycle for Moss Landing Facility.

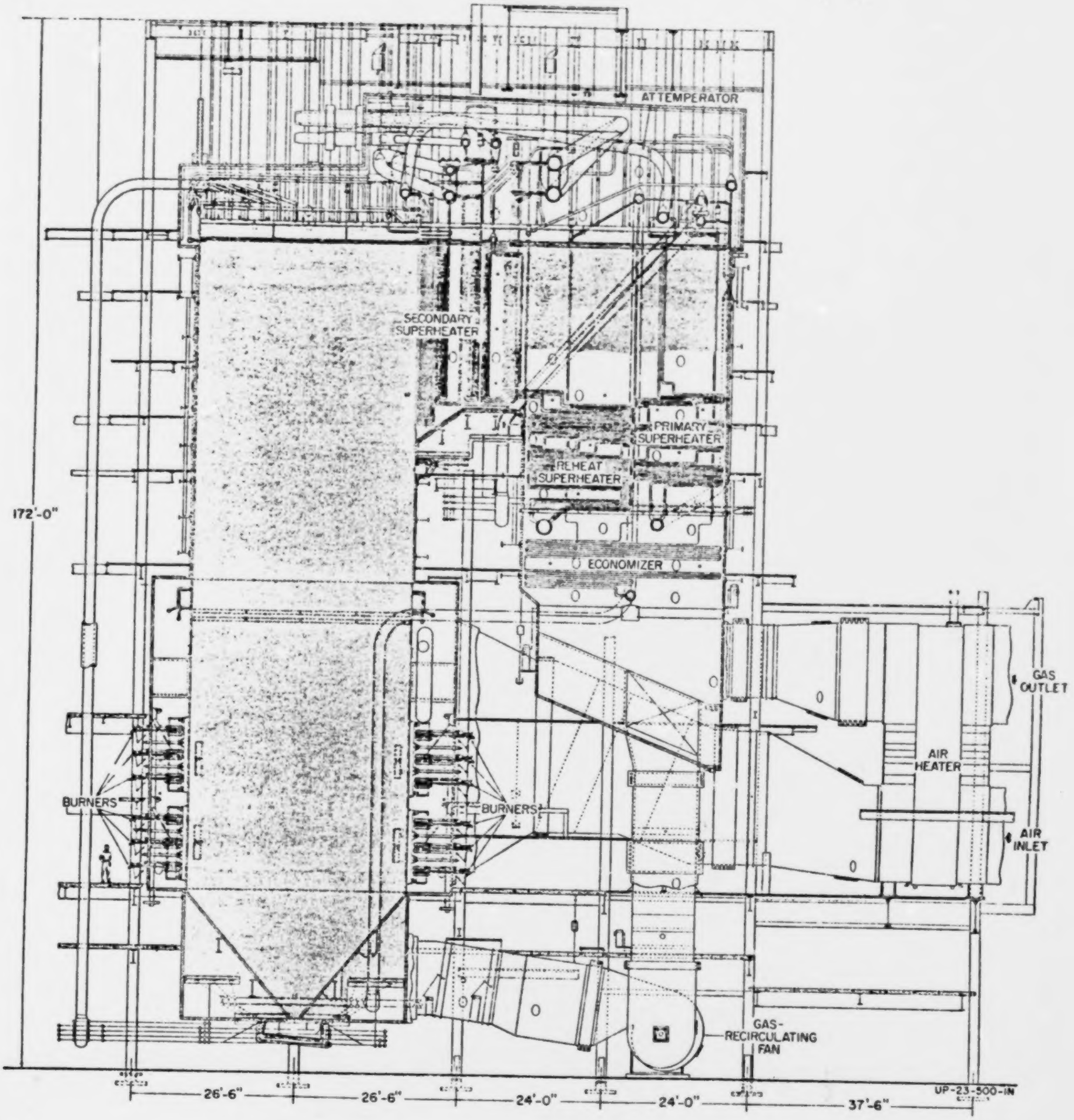

ATTEMPERATOR
SECONDARY SUPERHEATER
PRIMARY SUPERHEATER
REHEAT SUPERHEATER
ECONOMIZER
172'-0"
GAS OUTLET
AIR HEATER
AIR INLET
BURNERS
BURNERS
GAS-RECIRCULATING FAN
26'-6"
26'-6"
24'-0"
24'-0"
37'-6"
UP-23-500-IN

Figure 2-2. Pacific Gas and Electric Company Moss Landing Station Unit No. 6, Monterey County, California.

SECTION 3
TEST PLAN

The objective of this test program was to examine incremental changes in emissions and process operations as a result of combustion modification NO_x control. In order to assess incremental changes in emissions it was necessary to consider all influent and effluent streams. Process data were recorded periodically during each test so that changes in process operation could be examined.

3.1 UNIT OPERATION

The test program at Moss Landing enabled the examination of emissions and operations at three levels of NO_x control. The baseline, "as-designed", test represented the uncontrolled (for NO_x) level. The BOOS/FGR firing mode, which is the present operating mode for the Moss Landing boiler, represents the highest level of NO_x control. In this configuration, flue gas is recirculated into the boiler windbox, and the top row of burners admits no fuel. The lower elevations of burners admit fuel at greater than baseline rates. The third test configuration consisted of flue gas recirculation through the boiler windbox and all 48 burners in service.

Key operating parameters were held constant during the entire test program to simplify comparison between tests. All tests were conducted at a generator output of 710 MW. Other parameters held constant were steam temperature and steam pressure.

During each test, unit operation was to remain unchanged. The boiler was fired on a 1:1 mixture of residual oil and crude oil during the test program. The boiler had been fired on oil fuel only for two weeks prior to the tests with gas fuel used for start-up and shut down only. This provided a seasoned furnace characteristic of extended periods of oil firing.

3.2 SAMPLING AND ANALYSIS

The sampling and analysis procedure used in this test conform to a modified EPA Level 1 protocol (Reference 2). The modifications to the Level 1 protocol were:

- Atomic absorption spectroscopy was used for selected trace elements instead of spark source mass spectrometry
- Gas chromatography/mass spectrometry was used for identification and quantitation of Polycyclic Organic Matter (POM) and priority pollutants instead of low resolution mass spectrometry

These modifications were used to improve the quantitative aspects of the analyses. The methods used for particulate, sulfur species, and the continuous monitors for NO_x, O_2, CO, and CO_2 were also more quantitative than the Level 1 screening procedures for trace species.

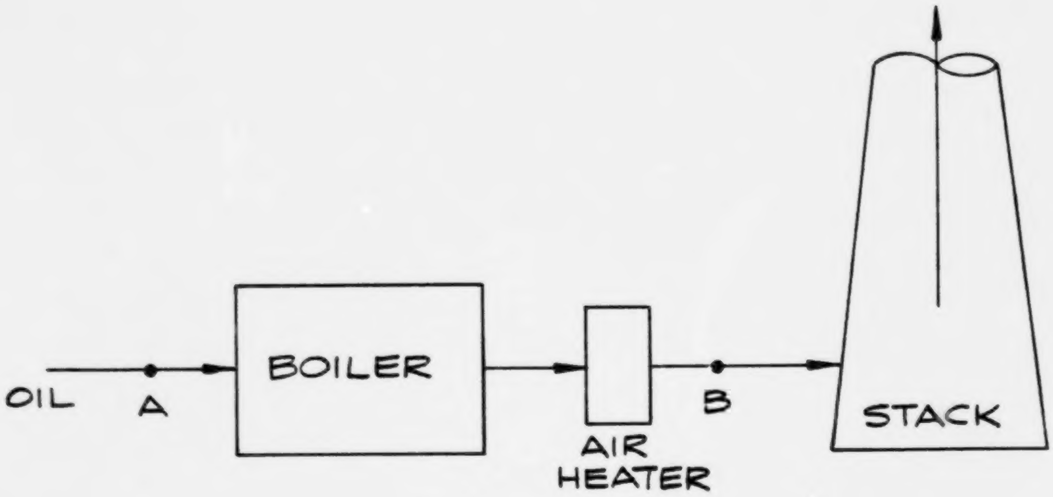
The purpose of these screening procedures is "to obtain preliminary environmental assessment information, identify problem areas, and provide the basis for the prioritization of streams, components, and classes of materials for further consideration in the overall assessment. As such, the results of the sampling and corresponding analysis procedures are quantitative within a factor of 2 to 3." (Reference 3).

3.2.1 Sampling

In order to evaluate incremental changes in emissions, influent and effluent streams must be analyzed. In this test program, the following samples were collected:

- Fuel
- Windbox O_2
- Flue gas
  - -- Continuous monitors NO_x, CO, CO_2, and O_2
  - -- Source Assessment Sampling System (SASS) and combined EPA Method 5 (particulate) and EPA Method 8 (sulfur species) at the air heater outlet
  - -- C_1-C_6 hydrocarbons by onsite GC

A schematic showing sampling point locations is given in Figure 3-1. Descriptions of the sampling methods are given in the following paragraphs. Since each test required several hours to perform, it was important that the methods obtain samples representative of the entire test.



Sampling location	Type of sample
A -- Oil	Grab sample -- oil
B -- Flue gas	Methods 5 and 8, SASS, gas grab sample for GC, continuous monitors

Figure 3-1. Sampling locations.

Oil Samples

Oil samples were obtained at the fuel inlet header. Each hour a 250 ml oil sample was taken at this location. The hourly samples for each test were mixed to give a representative composite sample for analysis.

Flue Gas Continuous Monitor

The flue gas continuous monitors were stationed in the north duct downstream of the air preheater. Sampling was continuous throughout the test. A description of the equipment used for continuous flue gas monitoring is shown in Table 3-1. The position of the continuous monitor sampling probe is shown on Figure 3-2. A schematic for the continuous sampling system is shown in Figure 3-3.

Particulate and Sulfur Species

Combined EPA Methods 5 and 8 sampling trains using Acurex High Volume Stack Sampler (HVSS) systems were used to obtain particulate loading and sulfur species concentrations at the air heater outlet. The sulfur species determined were gaseous SO_2 and SO_3 and particulate sulfate (SO_4=). The sampling locations of the HVSS systems are shown on Figure 3-2.

TABLE 3-1. FLUE GAS CONTINUOUS MONITORING

Instruments	Equipment Technique	Measuring Range
1. Thermo Electron Model 10A	Chemiluminescent	0 - 25 ppm 0 - 100 ppm 0 - 250 ppm 0 - 1000 ppm 0 - 2500 ppm 0 - 10000 ppm
2. CO Analyzer Anarad No. AR-500R	Nondispersive infrared absorption	0 - 1000 ppm
3. CO_2 Analyzer Anarad No. AR-500	Nondispersive infrared absorption	0 - 20 %
4. O_2 Analyzer Teledyne No. 326	Chemical fuel cell	0 - 5 % 0 - 10 % 0 - 25 %

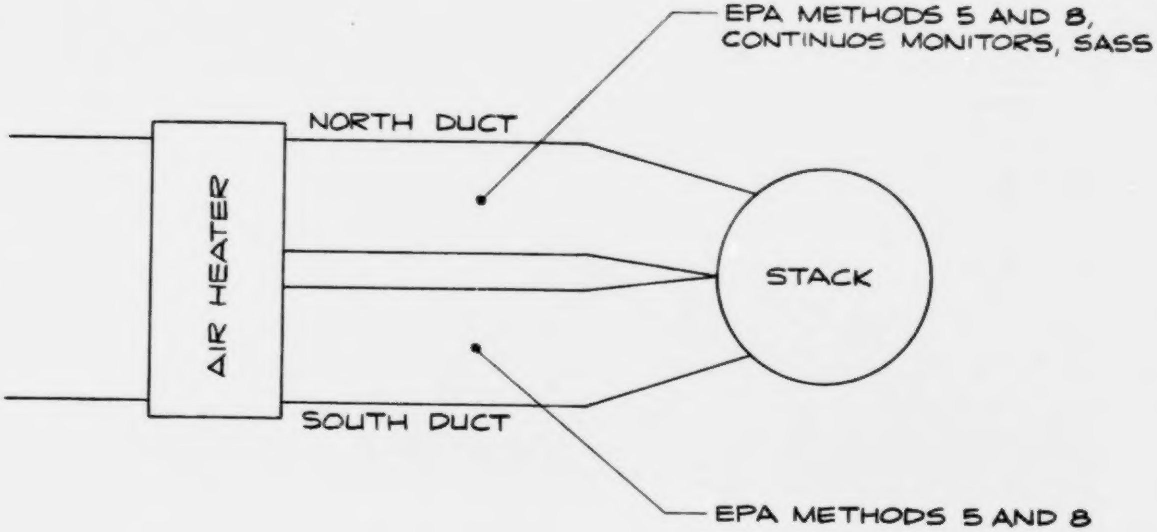

EPA METHODS 5 AND 8, CONTINUOS MONITORS, SASS
NORTH DUCT
AIR HEATER
STACK
SOUTH DUCT
EPA METHODS 5 AND 8

Figure 3-2. Gas sampling tests and locations.

1. *In situ* filter 0.6μ, 99.9999 percent efficient
2. Duct
3. 316 stainless steel probe
4. Four pass conditioner-dryer, 316 stainless steel internals
5. 3/8-inch unheated Polyflo
6. Teflon-lined sample pump
7. 3/8-inch unheated Teflon
8. Rotameter (typ 5 places)
9. 1/4-inch Polyflo tubing
10. Calibration gas manifold
11. Calibration gas selector valve (typ 3 places)
12. Calibration gas cylinders
13. Backpressure regulator
14. Auxiliary analysis port

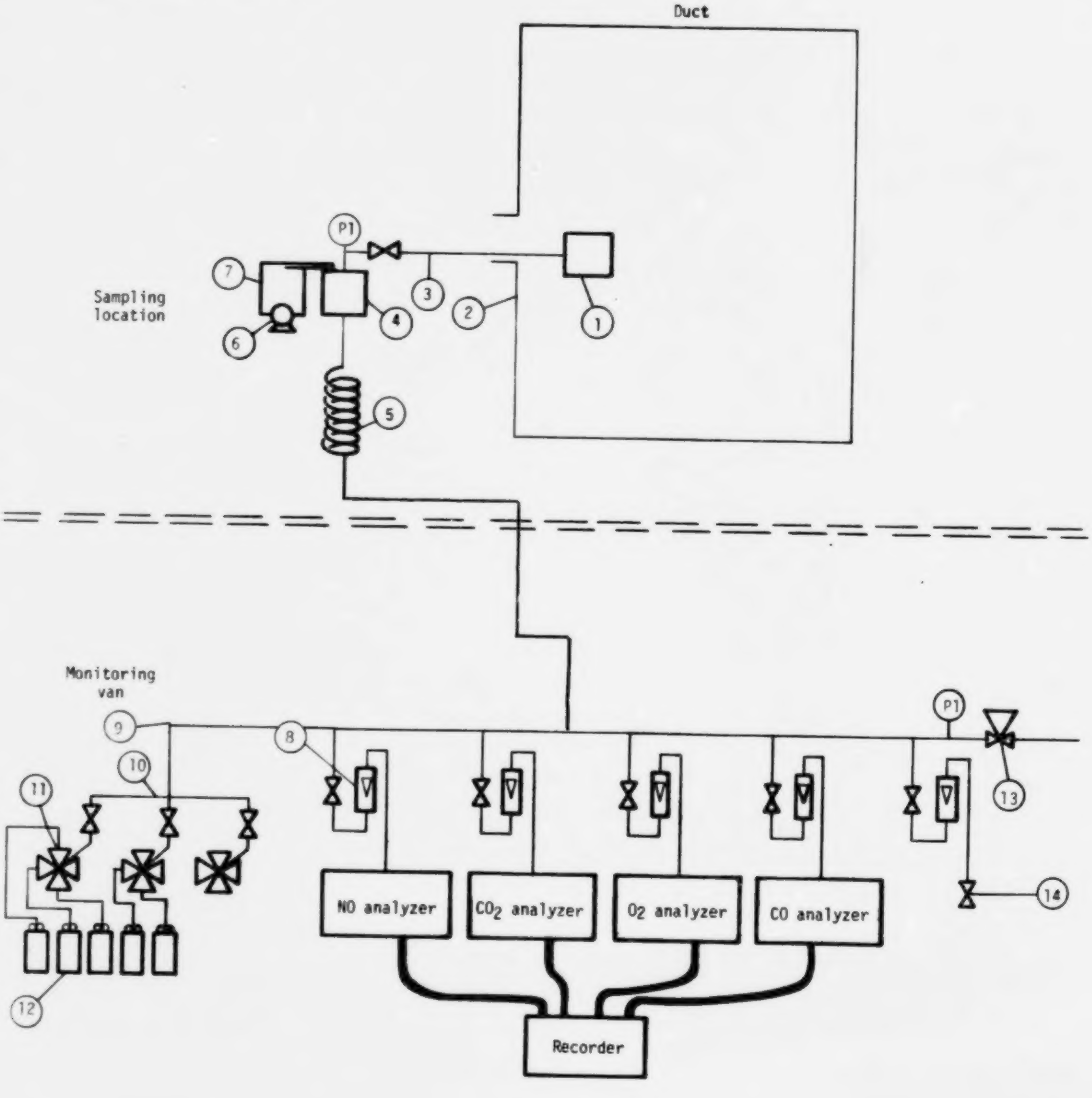

Duct
PI
7
6
4
3
2
1
5
Sampling location
Monitoring van
9
8
10
11
12
PI
13
14
NO analyzer
CO_2 analyzer
O_2 analyzer
CO analyzer
Recorder

Figure 3-3. Schematic for continuous extractive sampling system.

Source Assessment Sampling System

A Source Assessment Sampling System (SASS) train was used to sample the flue gas in the north duct leaving the air heater. Samples collected were used for trace element and organic species determinations in both vapor and condensed phases and also to provide trace element partitioning information.

The SASS train extracts the following samples:

Particulate: > 10 μm, 3-10 μm, 1-3 μm, 1 μm
Vapor Phase: XAD-2 porous polymer resin sorbent cartridge
Aqueous condensate
Hydrogen peroxide impinger
Ammonium persulfate-silver nitrate impingers

The sampling location of the SASS train is shown in Figure 3-2. A schematic of the SASS train is shown in Figure 3-4. The trace element analysis protocol is given in Appendix B. The organic analysis protocol is given in Appendix E.

C_1-C_6 Hydrocarbons

A gas grab sample was collected at the air heater outlet. The sample was collected in a gas sample bulb and then used to determine C_1-C_6 hydrocarbon compounds by using an onsite gas chromatograph. A Carle model 8500 portable gas chromatograph with flame ionization detector was used for this analysis.

3.2.2 Analysis

Table 3-2 lists the analyses performed on samples collected during each test. Descriptions of these analyses are given in the following paragraphs. Table 3-3 lists trace elements analyzed for in Moss Landing samples.

Operating Data Analysis

Key operating data (see Table 3-4) was collected approximately every 15 minutes during each test. This unit operating data was used to calculate unit efficiency and to verify that unit operating parameters were being maintained according to the test plan. The average values for the operating parameters are given in Appendix A. Unit efficiency was calculated using the Heat Loss Method, ASME Abbreviated Efficiency Test (Reference 4). Results of these calculations are given in Appendix A.

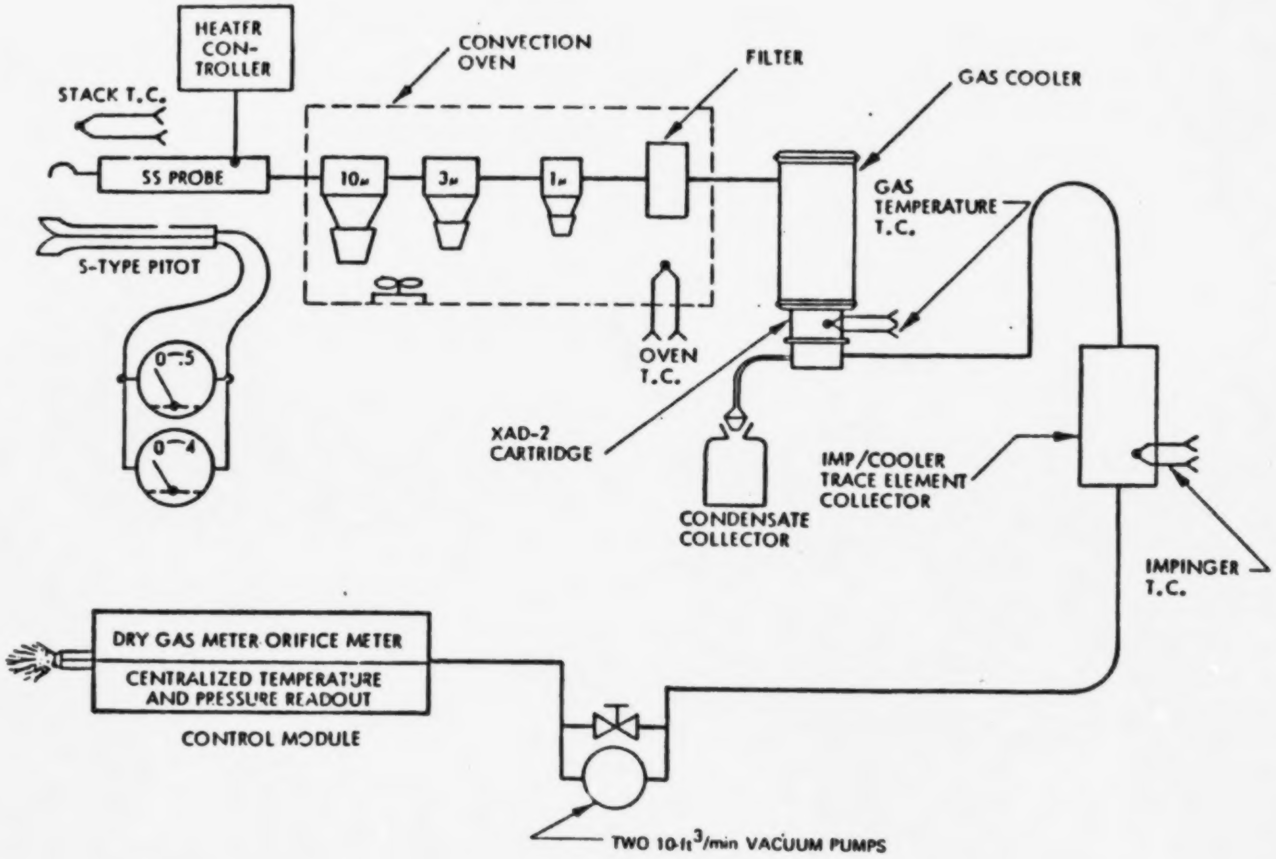

HEATER
CON-
TROLLER
CONVECTION
OVEN
FILTER
GAS COOLER
STACK T.C.
SS PROBE
10μ
3μ
1μ
GAS
TEMPERATURE
T.C.
S-TYPE PITOT
0–.5
0–4
OVEN
T.C.
XAD-2
CARTRIDGE
IMP/COOLER
TRACE ELEMENT
COLLECTOR
CONDENSATE
COLLECTOR
IMPINGER
T.C.
DRY GAS METER-ORIFICE METER
CENTRALIZED TEMPERATURE
AND PRESSURE READOUT
CONTROL MODULE
TWO 10-ft³/min VACUUM PUMPS

Figure 3-4. Source assessment sampling system (SASS) schematic (Reference 3).

TABLE 3-2. DATA AND SAMPLES COLLECTED

Operating Data	
Combustion Air	
Fuel	Proximate and Ultimate
	Trace elements
Flue Gas	NO_x, CO, CO_2, O_2
	Trace elements
	Vapor phase
	Condensed phase
	Sulfur species
	Organic material (per Level 1 supplemented by POM quantitation)
	C_1-C_6 hydrocarbons

TABLE 3-3. TRACE ELEMENTS ANALYZED FOR IN MOSS LANDING SAMPLES

Antimony
Arsenic
Barium
Beryllium
Bismuth

Boron
Cadmium
Chromium
Cobalt
Copper

Iron
Lead
Manganese
Mercury
Molybdenum

Nickel
Selenium
Tellurium
Thallium
Tin

Titanium
Uranium
Vanadium
Zinc
Zirconium

TABLE 3-4. KEY OPERATING DATA COLLECTED AT MOSS LANDING, UNIT 6

Steam

- Outlet temperature
- Outlet pressure
- Reheat inlet pressure
- Reheat inlet temperature
- Reheat outlet pressure
- Reheat outlet temperature
- Superheater inlet pressure
- Superheater inlet temperature

Water

- Feed flowrate
- Feed temperature
- Attemperation flow
- Attemperation temperature

Fuel

- Flowrate
- Fuel temperature

Inorganic Analyses

Trace element analyses for 25 selected trace elements (see Table 3-3) were performed on fuel, SASS particulate, XAD-2 and impinger solutions. The procedure used for each trace element is outlined in Appendix B, "Elemental Analysis Flowsheet." Proximate and ultimate, as well as trace element, analyses were conducted on fuel samples.

Organic Analyses

Organic analyses were performed in accordance with the EPA Level 1 protocol (References 2 and 5). The analyses included flue gas C_1-C_6 hydrocarbons, and organic material caught in the XAD-2 sorbent trap or retained in the condensate trap. The organic analysis techniques included IR, LRMS, and GC/MS. GC/MS was used for POM analysis (see Table 4-14). An outline of the organic analyses procedures is given in Appendix E.

SECTION 4
TEST PROGRAM RESULTS

Data from the test program provided information on unit operation, flue gas composition, particulate emissions, trace element emissions, sulfur species emissions, and organic species emissions. Data obtained are discussed in this section.

4.1 UNIT OPERATIONS

Unit operation was held essentially constant throughout each test. Key operating variables were controlled throughout the test program, so that tests could be compared to each other. A summary of the boiler operating conditions is given in Table 4-1. Detailed control room data are presented in Appendix A. The data in Appendix A and Table 4-1 are average values of the data recorded on 60-minute intervals during the test program.

TABLE 4-1. FURNACE OPERATING CONDITIONS

Test	Generator Output, MW	Oil Flow g/s (lb/sec)	Heat Input, MW (10^6 Btu/hr)	Flue Gas Flow Nm^3/MJ (scf/10^6 Btu)	Excess Air %
Baseline	710	40,800 (90)	1,766 (6,027)	0.29 (10,800)	17
BOOS/FGR	710	40,900 (90)	1,796 (6,129)	0.293 (10,900)	20
FGR	710	40,400 (89)	1,743 (5,949)	0.282 (10,500)	14

As can be seen in Table 4-1, excess air ranged from 14 percent for the FGR test to 20 percent for the BOOS/FGR test. Windbox O_2 for the FGR test averaged 19.7 percent. Windbox O_2 content for the BOOS/FGR test was not measured, but fan and damper settings were the same as for the FGR test. Therefore, windbox O_2 content should be approximately the same as in the FGR test. Windbox O_2 levels for the baseline test would be the same as ambient air levels.

Fuel analyses for each day of the test program are presented in Table 4-2. Very little day-to-day variation was seen in the fuel analysis. Also, there was little variation (approximately 3 percent) in heat input to the boiler.

Boiler efficiency for each of the tests was calculated using the abbreviated ASME efficiency method (Reference 4). The results of these calculations are given in Table 4-3; details of the calculations are given in Appendix A.

As can be seen in Table 4-3, boiler efficiency and heat rate remained fairly constant for all tests. Therefore, BOOS/FGR and FGR combustion modifications had no significant effect on boiler efficiency.

4.2 FLUE GAS COMPOSITION

Table 4-4 lists the results obtained from continuous gas sampling at the boiler outlet. As expected, NO_x levels decreased for the BOOS/FGR and FGR modes. Levels of NO_x in the flue gas were reduced about 43 percent from baseline for the BOOS/FGR test and about 26 percent for the FGR test.

The flue gas composition remained relatively constant throughout the tests except for the CO concentration. As can be seen in Table 4-4, the CO concentration was reduced about 30 percent from baseline in the BOOS/FGR test and 85 percent from baseline in the FGR test.

The changes in CO concentration in the flue gas can be related to differences in firing conditions between the three tests. Under BOOS/FGR firing, the air injected through the upper burners promotes good mixing; however, fuel flow to the burners in service must be increased to maintain load and therefore less complete combustion occurs at those burners. With all 48 burners in service, as in FGR firing, fuel flow to each burner is reduced, and good mixing is promoted by air flow through the burners. Therefore, best fuel-oxygen mixing occurs under FGR firing conditions.

TABLE 4-2. FUEL ANALYSES

	Baseline	BOOS/FGR	FGR
Ultimate Analysis			
Moisture	0.9	0.8	0.95
Carbon	84.25	84.26	84.44
Hydrogen	12.05	12.11	11.97
Nitrogen	0.25	0.23	0.27
Sulfur	0.21	0.25	0.31
Ash	0.05	0.05	0.05
Oxygen (diff)	2.29	2.30	2.01
Heating Value J/g (Btu/lb)	43,300 (18,600)	43,900 (18,900)	43,200 (18,600)
Specific Gravity	0.9	0.898	0.907

TABLE 4-3. BOILER EFFICIENCY

	Baseline	BOOS/FGR	FGR
Heat Input (% of Baseline)	100	102	99
Excess O_2 (% of Baseline)	100	117	82
Efficiency (%)	88.0	88.1	88.0
Heat Loss due to Dry Flue Gas (%)	3.84	3.76	3.75
Heat Rate $\left(\frac{\text{Electrical Output, MW}}{\text{Heat Input, MW}}\right)$	0.40	0.40	0.41

TABLE 4-4. FLUE GAS COMPOSITION

	Baseline	BOOS/FGR	FGR
O_2, %	3.3	3.7	2.8
CO_2, %	13.0	12.8	13.5
H_2O, %	12.0	11.5	11.8
NO_x			
(ppm @ 3% O_2 dry)	301	172	222
% of Baseline	100	57	74
CO (ppm @ 3% O_2 dry)	69	49	10
% of Baseline	100	70	15

4.3 PARTICULATE EMISSIONS

Particulate emissions were measured in both ducts of the boiler outlet. These measurements were obtained by using EPA Method 5 and SASS techniques. EPA Method 5 employs multipoint equal area sampling to measure particulate concentrations. Particulate concentration data from the EPA Method 5 sampling trains are presented in Table 4-5. SASS train sampling was also done on one of the boiler outlet ducts. The SASS train provides particulate concentration from a single point sample. This single point corresponds to the point of average flue gas velocity.

Particle size distribution information, which is usually determined from SASS cyclone particulate catches was not obtained for any of the tests. Particulate emissions from this unit were low. Therefore, cyclones on the SASS train, which were used during the first two tests, produced little particulate catch. The particulate concentration data obtained from SASS sampling is given in Table 4-6.

As can be seen in Tables 4-5 and 4-6, only very small quantities of particulates are emitted. Even though the amounts of particulates caught vary, the differences are very small. There appears to be no significant difference in particulate emissions between the various modes of low NO_x and baseline firing.

TABLE 4-5. EPA METHOD 5 PARTICULATE CONCENTRATION (μg/J)

	Baseline		BOOS/FGR		FGR	
	North	South	North	South	North	South
Boiler Outlet	0.024	0.022	0.018	0.014	0.022	0.022
Overall	0.022		0.016		0.022	

TABLE 4-6. SASS PARTICULATE CONCENTRATION (μg/J)*

	Baseline	BOOS/FGR	FGR
Boiler Outlet	0.007	0.008	0.007

*Concentration in one duct only

4.4 FUEL AND FLUE GAS TRACE ELEMENT CHARACTERIZATION AND EMISSIONS

Samples analyzed for trace element species at Moss Landing were the fuel and vapor and particulate phases of the flue gas. The detailed results of these analyses are given in Appendix C.

Once trace element concentrations were determined, trace element flowrates for each of the streams could be computed. The trace element flowrates are presented in Appendix D.

Solid/Vapor Partitioning of Trace Elements

Solid phase trace element concentrations were determined, from SASS train samples. Solid species collected on the filter in the SASS train were weighed and analyzed.

Vapor phase trace element concentrations were also obtained from the SASS train samples. The vapor phase species were collected in either the organics module (XAD-2) or the impinger portions of the SASS train. In the organics module, flue gas is cooled to approximately 290 K (68^{0}F) and passed through a porous polymer resin (XAD-2) cartridge. In this section, two samples are generated: the condensate and the XAD-2 sorbent. From the organics module, the flue gas goes through an impinger train with hydrogen peroxide and silver nitrate-ammonium persulfate solutions. For trace element analysis, the organic module aqueous condensate sample is combined with the hydrogen peroxide impinger sample for one sample of analysis. The organic module organic condensate is combined with the XAD-2 extract. Thus three vapor phase samples are analyzed: the XAD-2 and organic condensate, the aqueous condensate and hydrogen peroxide impinger solution, and the silver nitrate-ammonium persulfate impinger solution.

To determine which trace elements were concentrated in the vapor phase, trace element flowrates (Appendix D) were compared. Trace elements were considered to be concentrated in the vapor phase if their vapor phase concentrations were at least twice their solid phase concentrations. Trace elements were considered to be concentrated in the solid phase if their solid phase concentrations were at least twice their vapor phase concentrations. The partitioning results are given in Table 4-7.

The partitioning between solid and vapor is not greatly affected by the various modes of low NO_x firing. Only three elements exhibit a change in partitioning. Antimony, arsenic, and cobalt were observed in

TABLE 4-7. VAPOR-SOLID PARTITIONING

	Baseline	BOOS/FGR	FGR
Antimony	S	V	S
Arsenic	S	V	S
Barium	0	V	0
Beryllium	0	V	0
Bismuth	0	V	0
Boron	V	V	V
Cadmium	V	V	0
Chromium	V	V	V
Cobalt	S	V	S
Copper	0	V	V
Iron	V	V	V
Lead	0	V	0
Manganese	0	V	V
Mercury	0	0	0
Molybdenum	0	V	0
Nickel	V	V	V
Selenium	0	0	0
Tellurium	0	V	0
Thallium	0	V	0
Tin	0	V	0
Titanium	0	V	0
Uranium	0	V	0
Vanadium	0	S	0
Zinc	S	S	S
Zirconium	0	V	0

V = concentrated in vapor phase
S = concentrated in solid phase
0 = insufficient data

the solid phase fraction on the baseline and FGR tests and in the vapor phase fraction on the BOOS/FGR test.

4.5 SULFUR SPECIES EMISSIONS

Sulfur species were analyzed in all sample streams according to the following protocol:

- Oil -- sulfur by ultimate analysis
- Flue gas at boiler outlet -- SO_2 and SO_3 by Method 8 and $SO_4^=$ on particulate by turbidimetric method

With this information, a sulfur balance can be performed around the system.

The results of the sulfur species analyses are presented in Table 4-8. The results of the sulfur balance are shown in Table 4-9. The BOOS/FGR and FGR tests sulfur species balances closed within 15 percent. The baseline sulfur species balance was off by approximately 25 percent. The results presented in Table 4-10 were based on calculated flue gas flowrates.

Sulfur balance closure is sensitive to sulfur input flowrate. The sulfur input flowrate is dependent on fuel flowrate, sulfur content of the oil and specific gravity of the oil. Therefore, because of the uncertainty of the fuel analysis, there is uncertainty in the sulfur balances.

4.6 ORGANIC ANALYSES

Organic analyses were performed on the XAD-2 samples from the SASS train on the boiler outlet. Organic analyses were not performed on particulate fractions because insufficient particulate sample was collected. These analyses were done according to the EPA Level 1 protocol as outlined in Appendix E (References 2 and 4).

The samples were analyzed as follows: First, organics were extracted from the XAD-2 resin by methylene chloride in a Soxhlet apparatus. The extracts were then subjected to Total Chromatographable Organic (TCO) and gravimetric analyses which determine species with boiling points in the ranges of 373 K to 573 K (100^oC to 300^oC) and greater than 573 K (300^oC), respectively. Infrared spectra were also performed. If certain TCO and gravimetric concentration requirements were met, further analyses by liquid chromatography, with infrared and mass spectral analyses of the fractions eluted from the column, were performed. In addition flue gas C_1 to C_6 hydrocarbon compounds were analyzed onsite by gas chromatography. A discussion of the analytical results follows.

TABLE 4-8. SULFUR SPECIES ANALYSIS

Test	Species	Emissions		
		mg/M^3	ng/J	g/s
Baseline	SO_2 as $SO_4^{=}$			
	N duct	596	173	150
	S duct	635	184	166
	SO_3 as $SO_4^{=}$			
	N duct	9.7	2.8	2.4
	S duct	6.2	1.8	1.6
	$SO_4^{=}$			
	N duct	11.8	3.4	3.0
	S duct	10.4	3.0	1.0
BOOS/FGR	SO_2 as $SO_4^{=}$			
	N duct	610	179	167
	S duct	649	190	164
	SO_3 as $SO_4^{=}$			
	N duct	5.3	1.6	1.5
	S duct	17.1	5.0	4.3
	$SO_4^{=}$			
	N duct	--	--	--
	S duct	8.9	2.6	2.2
FGR	SO_2 as $SO_4^{=}$			
	N duct	669	189	165
	S duct	707	199	174
	SO_3 as $SO_4^{=}$			
	N duct	9.9	2.8	2.4
	S duct	6.5	1.8	1.6
	$SO_4^{=}$			
	N duct	15.9	4.5	3.9
	S duct	8.0	2.2	2.0

TABLE 4-9. SULFUR SPECIES BALANCE

	Baseline	BOOS/FGR	FGR
Sulfur Input			
Fuel feedrate (Kg/s)	40.8	40.9	40.4
Fuel sulfur content (%)	0.21	0.25	0.31
Sulfur input (g/s)	85.7	102.0	125.0
Sulfur Output			
SO_2 as $SO_4^=$ (g/s)	316.0	331.0	339.0
SO_3 as $SO_4^=$ (g/s)	4.0	5.8	4.0
$SO_4^=$ (g/s)	4.0	2.2	5.9
Total as sulfur (g/s)	108.0	113.0	116.0
Sulfur Recovery (%)	126	111	93

4.6.1 C_1 to C_6 Flue Gas Hydrocarbon Analyses

Onsite analyses of C_1 to C_6 flue gas hydrocarbons were conducted for the three tests. The flue gas grab samples were analyzed using a gas chromatograph/flame ionization detector. The results of the analyses are shown in Table 4-10.

4.6.2 Total Chromatographable Organics (TCO) and Gravimetric Analyses of Organic Extracts

Total Chromatographable Organics (TCO) and gravimetric analyses were performed on organic extracts of the combined XAD-2 and organic extract of condensate samples from the Baseline, BOOS/FGR and FGR tests.

Detailed analytical results are presented in Table 4-11. The results indicate that baseline operation produces more organics than either BOOS/FGR or FGR operation. The range of concentration of organics (TCO plus gravimetric) in the samples is 1.37 to 4.38 mg/M^3.

TABLE 4-10. FLUE GAS HYDROCARBON ANALYSIS FOR MOSS LANDING, CALIFORNIA

Test	Component	Concentration (ppm @ 3% O_2)
Baseline	No peaks	--
BOOS/FGR	CH_4	0.05
FGR	No peaks	--

To qualify for liquid column separation, an uncorrected sample extract was required to contain at least 15 mg/ml of organic material in 2 ml of solution. Only the baseline sample met this criteria.

4.6.3 Infrared and Gas Chromatographic Mass Spectral Analysis of Total Extracts

The total sample extracts were analyzed by infrared spectrophotometry (IR) and Gas Chromatography/Mass Spectrometry (GC/MS). The infrared spectrophotometry results are shown in Table 4-12. The samples show some evidence of phthalate or benzoic acid contamination. GC/MS Analyses for the compounds listed in Table 4-13 were performed. This list includes polycyclic organic matter and priority pollutants. The results of GC/MS analyses are shown in Table 4-14.

The major species seen in the XAD-2 extracts are polynuclear aromatics and phthalate contaminants. The phthalates, especially bis(2-ethylhexyl) are present in the samples at higher levels than seen in laboratory blanks. Again, this is probably due to contamination.

4.6.4 Column Chromatography

The XAD-2 sample from the baseline test was separated via column chromatography. Gravimetric and TCO content were then obtained for each fraction. Results of this analysis are given in Table 4-15.

4.6.5 Infrared and Mass Spectral (GC/MS and LRMS) Analyses of Fractions from Column Chromatography

The total samples obtained from column chromatography fractionation of the baseline XAD-2 sample were split and analyzed by using Level 1

TABLE 4-11. RESULTS OF GRAVIMETRIC AND TCO ANALYSIS OF XAD-2 EXTRACT

Test	Gravimetric Result (mg)	TCO Result (mg)	Total Organics in Extract (mg)	Total (mg/M^3)
Baseline	113	8.9	122	4.38
BOOS/FGR	15.9	23.4	39	1.43
FGR	28.5	10.7	39	1.37

TABLE 4-12. SUMMARY OF ABSORBANCES FOUND IN SAMPLES, BUT NOT IN METHOD BLANK FOR XAD-2

Test	Frequency, cm^{-1}	Possible Assignment
Baseline	2490 1940 1400, 1370 1250 - 1260	$C \equiv N$ Imide or Anhydride Methyl, Aliphatic bending C-O
BOOS/FGR	2950, 2920, 2840 1740 1600 1450 1380 1285 - 1260	Aliphatic CH Carboxyl Aromatic $C = C$ Methyl, Aliphatic bend Methyl, Aliphatic bend C-O
FGR	2940 1940/2040 1255	$C \equiv N$ Imide or Anhydride C-O

TABLE 4-13. COMPOUNDS FOR WHICH GC/MS ANALYSIS WAS PERFORMED IN THE MOSS LANDING XAD-2 EXTRACTS

* acenaphthene
* acenaphthylene
* anthanthrene
* anthracene
* benzidine
* benzo(a)anthracene
* 3,4-benzofluoranthene
* benzo(k)fluoranthene
* benzo(ghi)perylene
* benzo(a)pyrene
* benzo(e)pyrene
* 4-bromophenyl phenyl ether
* butyl benzyl phthalate
* bis(2-chloroethoxy) methane
* bis(2-chloroethyl)ether
* bis(2-chloroisopropyl) ether
* 2-chloronaphthalene
* 4-chlorophenyl phenyl ether
* chrysene
* dibenzo(a,h)anthracene

dibenzo(c,g)carbazole
dibenzo(a,h)pyrene
dibenzo(a,i)pyrene

* di-n-butyl phthalate
* 1,2 dichlorobenzene
* 1,3 dichlorobenzene
* 1,4 dichlorobenzene
* bis (2-ethylhexyl) phthalate
* 3,3' dichlorobenzidine
* diethyl phthalate
* 7,12 dimethyl benz(a) anthracene

dimethyl phthalate

* 2,4-dinitrotoluene
* 2,6-dinitrotoluene
* di-n-octyl phthalate
* 1,2-diphenylhydrazine (as azobenzene)
* fluoranthene
* fluorene
* hexachlorobenzene
* hexachlorobutadiene
* hexachlorocyclopentadiene
* hexachloroethane
* indeno(1,2,3-cd)pyrene
* isophorone
* 3-methyl cholanthrene
* naphthalene
* nitrobenzene
* N-nitrosodiphenylamine
* N-nitrosodi-n-propylamine

perylene

* phenanthrene
* pyrene

2,3,7,8-tetrachlorodibenzo-p-dioxin

* 1,2,3-trichlorobenzene

*Compound in calibration standard

TABLE 4-14. ORGANICS DETECTED IN MOSS LANDING XAD-2 EXTRACTS

Compound	Concentration mg/m^3		
	Baseline	BOOS/FGR	FGR
Dichlorobenzene	--	0.1	--
Fluorene	--	0.1	--
Phenanthrene/anthracene	0.1	0.7	0.2
Fluoranthene	--	0.1	0.1
Pyrene	--	0.2	--
Bis (2-ethythexyl) phthalate	--	120	5.0
Chrysene/Benz (a) anthracene	--	0.1	--

infrared and mass spectral techniques. Table 4-16 presents the infrared analyses of the baseline XAD-2 column chromatographic fractions. Fractions LC2 and LC3 were analyzed by GC/MS for polycyclic organic matter. No polycyclic organic matter could be detected to a limit of 50 ng/m^3.

Combined fractions LC4 and LC5 and fraction LC6 and LC7 were analyzed by Low Resolution Mass Spectrometry (LRMS). No species could be detected above background in any LRMS analysis.

4.6.6 Summary of Organic Analyses

Comparison of the organic emissions of the three tests indicate that baseline operation produces greater organic emissions than BOOS/FGR or FGR operation. The baseline test organic samples were analyzed by infrared spectrophotometry, low resolution mass spectrometry, column chromatography, and gas chromatography/mass spectrometry. The results of infrared investigation are inconclusive because of sample contamination. No species could be found by low resolution mass spectrometry above background. The XAD-2 extracts from all three tests were analyzed by GC/MS. The BOOS/FGR XAD-2 extract was found to contain the greatest amounts of polynuclear

TABLE 4-15. GRAVIMETRIC AND TCO RESULTS OF COLUMN CHROMATOGRAPHY OF THE BASELINE XAD-2 SAMPLE

	TCO		GRAV		TOTAL	
Fraction	g/M^3	pg/J	μg/M^3	pg/J	μg/M^3	pg/J
LC1	0.359	0.051	8.97	1.27	9.3	1.32
LC2	5.38	0.764	12.6	1.79	18.0	2.55
LC3	8.97	1.27	1670.0	237.0	1680.0	238.0
LC4	0.359	0.051	383.0	54.4	383.0	54.5
LC5	14.3	2.03	178.0	25.3	192.0	27.3
LC6	0.359	0.051	642.0	91.2	642.0	91.3
LC7	0.359	0.051	57.4	8.16	57.8	8.21

TABLE 4-16. INFRARED ANALYSIS OF COLUMN CHROMATOGRAPHIC FRACTIONS[a]

Fraction	Frequency (cm^{-1})	Possible Assignment
LC1	1370	CH_3/alkane bending
LC3	2960, 2900	Aliphatic C-H
	1400	CH_3 aliphatic bending
	1255	C-O ether
	1100 - 1000	C-O-C symmetrical
LC4	2960,2900	Aliphatic C-H
	2495	C N
	2040, 1940	Imide or Anhydride
	1400, 1370	Aliphatic bending
	1255	C-O ether
	1100 - 1000	C-O-C symmetrical
LC5	2900, 2840	Aliphatic C-H
	1400	Aliphatic bending
	1255	C-O ether
	1100 - 1000	C-O-C symmetrical
LC6	2950, 2910	Aliphatic C-H
	1600	Aromatic C=C
	1450, 1420	Aliphatic bending
	1280 - 1240	Carboxylic acid C-O
	1120 - 1010	Distorted symmetrical C-O-C of ether
LC7	3600, 3100	Hydroxyl
	2840	Aliphatic CH
	1730	Carboxyl
	1430, 1370	Aliphatic C-C-H bending
	1260 - 1230	C-O
	1090,1010	C-O stretching

[a] Nothing visible in spectrum of LC2

aromatic compounds. Column chromatography fractions of the baseline XAD-2 extract were also analyzed by GC/MS. No polycyclic organic matter was found in these fractions.

4.6.7 Bioassays

Mutagenicity and cytotoxicity evaluations of the BOOS/FGR XAD-2 extract were also done. The mutagenicity was evaluated using the Ames test (Reference 5). In this test, the compound is tested at four concentrations. The results indicate that the test compound is not toxic and did not induce any mutagenic activity in any of the test organisms employed in these assays. The Bioassay Test Report is presented in Appendix F.

The cytotoxicity of the XAD-2 extract was evaluated by the WI-38 Human Cell Cytotoxicity Assay. The test results indicate that the XAD-2 extract is moderately toxic to WI-38 cells. The Bioassay Test Report is presented in Appendix F.

SECTION 5
SUMMARY

The test program conducted on Unit 6 of PG&E's Moss Landing Power Plant compared changes in unit operation and emissions resulting from NO_x control implementation. The results of a baseline or "as-designed" operation test were compared to test results from replicate tests at two different levels of NO_x control. These two levels of NO_x control, burners-out-of-service/flue gas recirculation (BOOS/FGR) and flue gas recirculation alone (FGR) achieved 43 percent and 26 percent reductions in NO_x from the baseline level, respectively. Summaries of the effects on boiler operation and emissions are given below.

Operation

Steam temperatures were maintained at about 815 K (1000°F) during the test program. Also, reheat attemperation did not change throughout the test program, therefore there was little change in cycle efficiency.

The combustion modifications for the BOOS/FGR test consisted of admitting no fuel through the top row of burners and operating the lower burners fuel rich, combined with flue gas recirculation into the windbox. An intermediate level of NO_x control was also tested using flue gas recirculation through the burners only. Low excess air firing was used under both conditions. To maintain safe operations under these firing modes, more operator vigilance may be required. If excess air levels are reduced too much, poor fuel utilization and excursions in carbon monoxide concentration can result. Moreover, if windbox O_2 concentration decreases significantly because of too much flue gas recirculation, incomplete combustion could result, which can also raise CO concentrations in the flue gas.

Operation of this boiler under the various modes of combustion modification firing did not require reducing the boiler load. Maximum generator boiler output capacity is 739 MW. For all three tests, generator boiler output was maintained at 710 MW. Also, the different firing modes did not affect boiler efficiency.

Emissions

Emissions were examined for changes due to NO_x controls. Gaseous, particulate, trace element, sulfur species, and organic emissions were evaluated. The test program results are discussed briefly in the following paragraphs.

Gaseous NO_x, CO, O_2, and CO_2 were measured by continuous monitors during the tests. NO_x controls resulted in emissions reductions from baseline levels of 43 percent for BOOS/FGR firing and 26 percent for FGR firing. CO levels were maintained well below 100 ppm for all tests. For the combustion modification tests, CO was maintained below 50 ppm. Flue gas in the FGR test had the lowest CO content of all operating modes.

An EPA Method 8 train was used to collect SO_2 and SO_3 samples from the flue gas. Flue gas SO_2 levels were found to vary depending on fuel sulfur and not with firing mode. Also the percent of fuel sulfur which was oxidized to SO_3 was not significantly affected by firing mode.

Particulate testing showed that there was no difference in particulate emissions levels between the two combustion modification techniques and baseline firing. Also, because little particulate was found in the SASS cyclone catches, no conclusion could be drawn from particle size distribution.

Trace element tests showed that trace element partitioning was not greatly affected by the various modes of combustion modification firing. However, because of the difficulty of analysis of the small amount of ash collected, no conclusion as to the effect of combustion modifications on trace element partitioning could be reached.

The organic emissions from all three tests were compared. The largest amount of organics were found in the XAD-2 extract when under baseline operation. The XAD-2 extract from the baseline test was separated via liquid chromatography. Organic concentrations in the BOOS/FGR and FGR tests were not high enough to warrant liquid chromatographic separation. The XAD-2 extract from all tests were subjected to gas chromatography/mass spectrometry analysis. This analysis showed the BOOS/FGR XAD-2 extract to contain the largest amount of polycyclic organic matter. The liquid chromatographic fractions from the baseline sample were also analyzed by GC/MS and Low Resolution Mass Spectrometry (LRMS). No polycyclic organic matter could be detected in these fractions by either analysis.

Cytotoxicity and mutagenicity tests were done on the BOOS/FGR XAD-2 extract. The extract was found to possess nondetectable toxicity and did not cause any mutagenic activity in the Ames test. However, the extract was found to be moderately toxic to WI-38 cells.

REFERENCES

1. Mason, H. B., et al., "Preliminary Environmental Assessment of Combustion Modification Techniques: Volume II, Technical Results," EPA-600/7-77-119b, October 1977.

2. Lentzen, D. E., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment (Second Edition)," EPA-600/7-78-201, October 1978.

3. Hammersma, J. W., et al., "IERL-RTP Procedures Manual: Level 1 Environmental Assessment," EPA-600/2-76-160a, June 1976.

4. "Performance Test Code Steam Generating Units," PTC 4.1, American Society of Mechanical Engineers, 1965.

5. "IERL-CRB Analysis Manual for Level 1 Environmental Assessment," ADL-783467-10-2, February 1977.

APPENDIX A
OPERATING DATA AND EFFICIENCY TEST RESULTS

Symbols appearing in the tables:

AH	Airheater
BFP	Boiler Feed Pump
DA	De-aerator
FD	Forced Draft
FW	Feedwater
GR	Gas Recirculation
HP	High Pressure
LP	Low Pressure
PSH	Primary Superheater
RH	Reheater
SH	Superheater

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Date Test		9/12/78 BOOS/FGR	9/14/78 Baseline	9/15/78 FGR
Fuel Oil To Burner Temp.	°F	129	129	127
Temp. Wet Bulb	°F	58.7	59	59.7
Temp. Dry Bulb	°F	63.7	62	62.7
Barometric Press.	in HG	29.9	30.0	30.1
FW Flow	MLB/hr	5040	5030	4981
FW Press.	PSIG	4290	4300	4300
Cold Reheat Press.	PSIG	628	630	643
Hot Reheat Press.	PSIG	588	597	616
Ext. Stm to Htr 1A Temp.	°F	671	671	674
Drain Temp. Htr 1B	°F	499	500	502
FW Inlet to Htr 1A Temp.	°F	476	477	479
FW Outlet from Htr 1A Temp.	°F	536	537	538
Ext. Stm to Htr 1B Temp.	°F	663	662	665
Drain Temp. Htr, 1B	°F	507	508	510
FW Inlet to Htr 1B Temp.	°F	475	476	478
FW Outlet from Htr 1B Temp.	°F	536	536	537
Gas Temp. Entering AH #1	°F	700	705	700
Gas Temp. Leaving AH #1	°F	262	266	264
Air Temp. Entering AH #1	°F	82	80	77
Air Temp. Leaving AH #1	°F	573	579	574
Gas Temp. Entering AH #2	°F	700	704	695
Gas Temp. Leaving AH #2	°F	262	263	260
Air Temp. Entering AH #2	°F	84	82	79
Air Temp. Leaving AH #2	°F	561	566	560
Stm Leaving PSH Temp. #1	°F	841	836	850
Stm Leaving PSH Temp. #2	°F	846	839	844
Ext. Stm to Htr 1A/1B Press	PSIG	934	938	945
Ext. Stm to Htr 2A Temp	°F	554	554	561
Drain Temp. Htr 2A	°F	424	425	424
FW Inlet to Htr 2A	°F	405	406	412
Ext. Stm to Htr 2B Temp.	°F	555	554	561
Drain Temp. Htr 2B	°F	424	425	424
FW Inlet to Htr 2B Temp.	°F	411	413	411
DA Storage Temp.	°F	355	356	355

Date		9/12/78	9/14/78	9/15/78
Test		BOOS/FGR	Baseline	FGR
Time				
HP Turbine Inlet T	°F	1000	1000	1000
LP Turbine Inlet T	°F	1000	1000	1000
FD Fan Amps 6-2	AMPS	572	501	520
FD Fan Amps 6-1	AMPS	569	494	503
GR Fan Amps 6-2	AMPS	127	133	125
GR Fan Amps 6-1	AMPS	128	130	127
SH Spray S	%	50	52	52
SH Spray N	%	49	50	51
RH Spray	%	100	100	100
FD Fan #2 Damper S	%	93	86	86
FD Fan #1 Damper N	%	97	91	90
GR to Air Foil 6-2	%	100	0	100
GR to Hopper 6-2	%	0	100	0
GR to Air Foil 6-1	%	100	0	100
GR to Hopper 6-1	%	0	100	0
GR Fan #2 Damper	%	55	54	58
GR Fan #1 Damper	%	59	57	64
Unit Load	MW	710	710	710
Cold Reheat Press.	PSIG	628	630	643
Condenser Vacuum	in HG	29.0	29.1	29.1
SH Damper S/N	%	95/99	95/99	56/58
RH Damper S/N	%	49/56	48/56	78/80
SH Spray Flow S	MLB/HR	149	162	165
SH Spray Flow N	MLB/HR	149	162	164
RH Spray Flow S	MLB/HR	44	43	43
RH Spray Flow N	MLB/HR	47	46	43

Date Test Time		9/12/78 BOOS/FGR	9/14/78 Baseline	9/15/78 FGR
Fuel Oil Burner Diff. Press.	PSIG	239	220	230
Fuel Oil Burner Supply Press.	PSIG	1025	1100	1100
Fuel Oil Burner Return Press.	PSIG	787	882	870
Air Htr Gas Inlet Press. #2	in H_2O	6.5	6.0	5.9
Air Htr Gas Inlet Press. #1	in H_2O	6.3	5.8	5.6
Windbox to Furnace Diff.	in H_2O	3.4	2.5	3.2
Furnace Press.	in H_2O	23	22.4	22
Windbox Press.	in H_2O	26.3	24.8	25
FD Fan Disch. Press. #2	in H_2O	36	33	34.4
FD Fan Disch. Press. #1	in H_2O	36	33	34.6
Superheater Outlet Press.	PSIG	3710	3710	3700
BFP Disch. Press. #2	PSIG	4400	4400	4394
BFP Disch. Press. #1	PSIG	4400	4400	4398
Fuel Flow	Relative	5.6	5.6	5.5
O_2	%	2.0	2.0	2.0
Sec. SH Outlet Temp. N	^{o}F	1005	1010	1012
Sec. SH Outlet Temp. S	^{o}F	1005	1010	1012
Sec. SH Inlet Temp. N	^{o}F	814	823	828
Sec. SH Inlet Temp. S	^{o}F	819	830	835
Reheat SH Outlet Temp. N	^{o}F	1005	1010	1012
Reheat SH Outlet Temp. S	^{o}F	1005	1012	1012
Reheat SH Inlet Temp. N	^{o}F	532	530	544
Reheat SH Inlet Temp. S	^{o}F	553	550	562
Turb. Adm. Press.	PSIG	3677	3680	3680
Fuel Supply Integrator	10^2 Gal	3442	2637	2190
Fuel Return Integrator	10^2 Gal	1016	555	481
Time Between Reading	Min	330	284	238

SUMMARY SHEET

ASME TEST FORM
FOR ABBREVIATED EFFICIENCY TEST

PTC 4.1-a (1964)

OWNER OF PLANT PG&E
TEST NO. BASELINE BOILER NO. 7 DATE 9/14/78
LOCATION
TEST CONDUCTED BY
OBJECTIVE OF TEST
DURATION
BOILER, MAKE & TYPE
RATED CAPACITY
STOKER, TYPE & SIZE
PULVERIZER, TYPE & SIZE
BURNER, TYPE & SIZE
FUEL USED
MINE
COUNTY
STATE
SIZE AS FIRED

PRESSURES & TEMPERATURES

1	STEAM PRESSURE IN BOILER DRUM	psia	
2	STEAM PRESSURE AT S. H. OUTLET	psia	3725
3	STEAM PRESSURE AT R. H. INLET	psia	645
4	STEAM PRESSURE AT R. H. OUTLET	psia	612
5	STEAM TEMPERATURE AT S. H. OUTLET	F	1010
6	STEAM TEMPERATURE AT R.H. INLET	F	540
7	STEAM TEMPERATURE AT R.H. OUTLET	F	1010
8	WATER TEMP. ENTERING (ECON.)(BOILER)	F	537
9	STEAM QUALITY % MOISTURE OR P. P. M.		
10	AIR TEMP. AROUND BOILER (AMBIENT)	F	62
11	TEMP. AIR FOR COMBUSTION (This is Reference Temperature) †	F	81
12	TEMPERATURE OF FUEL	F	129
13	GAS TEMP. LEAVING (Boiler) (Econ.) (Air Htr.)	F	264
14	GAS TEMP. ENTERING AH (If conditions to be corrected to guarantee)	F	

UNIT QUANTITIES

15	ENTHALPY OF SAT. LIQUID (TOTAL HEAT)	Btu/lb	533
16	ENTHALPY OF (SATURATED) (SUPERHEATED) STM.	Btu/lb	1422
17	ENTHALPY OF SAT. FEED TO (BOILER) (ECON.)	Btu/lb	533
18	ENTHALPY OF REHEATED STEAM R.H. INLET	Btu/lb	1253
19	ENTHALPY OF REHEATED STEAM R. H. OUTLET	Btu/lb	1521
20	HEAT ABS/LB OF STEAM (ITEM 16 – ITEM 17)	Btu/lb	890
21	HEAT ABS/LB R.H. STEAM (ITEM 19 – ITEM 18)	Btu/lb	268
22	DRY REFUSE (ASH PIT + FLY ASH) PER LB AS FIRED FUEL	lb/lb	0
23	Btu PER LB IN REFUSE (WEIGHTED AVERAGE)	Btu/lb	0
24	CARBON BURNED PER LB AS FIRED FUEL	lb/lb	0.8425
25	DRY GAS PER LB AS FIRED FUEL BURNED	lb/lb	16.33

HOURLY QUANTITIES

26	ACTUAL WATER EVAPORATED	lb/hr	5031000
27	REHEAT STEAM FLOW	lb/hr	4191000
28	RATE OF FUEL FIRING (AS FIRED wt)	lb/hr	323000
29	TOTAL HEAT INPUT $\frac{(\text{Item 28} \times \text{Item 41})}{1000}$	kB/hr	6027000
30	HEAT OUTPUT IN BLOW-DOWN WATER	kB/hr	106,200
31	TOTAL HEAT OUTPUT $\frac{(\text{Item 26} \times \text{Item 20}) + (\text{Item 27} \times \text{Item 21})}{1000}$ + Item 30	kB/hr	5601000

FLUE GAS ANAL. (BOILER)(ECON) (AIR HTR) OUTLET

32	CO_2	% VOL	13.0
33	O_2	% VOL	3.3
34	CO	% VOL	0
35	N_2 (BY DIFFERENCE)	% VOL	83.7
36	EXCESS AIR	%	17

FUEL DATA

	COAL AS FIRED PROX. ANALYSIS	% wt
37	MOISTURE	
38	VOL MATTER	
39	FIXED CARBON	
40	ASH	
	TOTAL	
41	Btu per lb AS FIRED	
42	ASH SOFT TEMP.* ASTM METHOD	

	OIL	
51	FLASH POINT F*	
52	Sp. Gravity Deg. API*	
53	VISCOSITY AT SSU* BURNER SSF	
44	TOTAL HYDROGEN % wt	
41	Btu per lb	18672

	COAL OR OIL AS FIRED ULTIMATE ANALYSIS	
43	CARBON	84.25
44	HYDROGEN	12.05
45	OXYGEN	2.29
46	NITROGEN	0.25
47	SULPHUR	0.21
40	ASH	0.05
37	MOISTURE	0.9
	TOTAL	100.0

	GAS	% VOL
54	CO	
55	CH_4 METHANE	
56	C_2H_2 ACETYLENE	
57	C_2H_4 ETHYLENE	
58	C_2H_6 ETHANE	
59	H_2S	
60	CO_2	
61	H_2 HYDROGEN	
	TOTAL	
	TOTAL HYDROGEN % wt	
62	DENSITY 68 F ATM. PRESS.	
63	Btu PER CU FT	
41	Btu PER LB	

	COAL PULVERIZATION	
48	GRINDABILITY INDEX*	
49	FINENESS % THRU 50 M*	
50	FINENESS % THRU 200 M*	

64 INPUT-OUTPUT EFFICIENCY OF UNIT % $\frac{\text{ITEM 31} \times 100}{\text{ITEM 29}}$ 93

	HEAT LOSS EFFICIENCY	Btu/lb A. F. FUEL	% of A. F. FUEL
65	HEAT LOSS DUE TO DRY GAS	717	3.84
66	HEAT LOSS DUE TO MOISTURE IN FUEL	10.1	0.05
67	HEAT LOSS DUE TO H_2O FROM COMB. OF H_2	1214	6.51
68	HEAT LOSS DUE TO COMBUST. IN REFUSE		
69	HEAT LOSS DUE TO RADIATION		0.21
70	UNMEASURED LOSSES		1.5
71	TOTAL		12.11
72	EFFICIENCY = (100 – Item 71)		87.89

* Not Required for Efficiency Testing

† For Point of Measurement See Par. 7.2.8.1-PTC 4.1-1964

SUMMARY SHEET

ASME TEST FORM
FOR ABBREVIATED EFFICIENCY TEST

PTC 4.1-a (1964)

TEST NO. B005/FGR BOILER NO. 7 DATE 9/12/78

OWNER OF PLANT PG&E LOCATION

TEST CONDUCTED BY OBJECTIVE OF TEST DURATION

BOILER, MAKE & TYPE RATED CAPACITY

STOKER, TYPE & SIZE

PULVERIZER, TYPE & SIZE BURNER, TYPE & SIZE

FUEL USED MINE COUNTY STATE SIZE AS FIRED

PRESSURES & TEMPERATURES

1	STEAM PRESSURE IN BOILER DRUM	psia	
2	STEAM PRESSURE AT S. H. OUTLET	psia	3721
3	STEAM PRESSURE AT R. H. INLET	psia	643
4	STEAM PRESSURE AT R. H. OUTLET	psia	603
5	STEAM TEMPERATURE AT S. H. OUTLET	F	1005
6	STEAM TEMPERATURE AT R.H. INLET	F	554
7	STEAM TEMPERATURE AT R.H. OUTLET	F	1005
8	WATER TEMP. ENTERING (ECON.)(BOILER)	F	536
9	STEAM QUALITY % MOISTURE OR P. P. M.		
10	AIR TEMP. AROUND BOILER (AMBIENT)	F	64
11	TEMP. AIR FOR COMBUSTION (This is Reference Temperature) †	F	83
12	TEMPERATURE OF FUEL	F	129
13	GAS TEMP. LEAVING (Boiler) (Econ.) (Air Htr.)	F	262
14	GAS TEMP. ENTERING AH (If conditions to be corrected to guarantee)	F	

UNIT QUANTITIES

15	ENTHALPY OF SAT. LIQUID (TOTAL HEAT)	Btu/lb	531.5
16	ENTHALPY OF (SATURATED) (SUPERHEATED) STM.	Btu/lb	1418
17	ENTHALPY OF SAT. FEED TO (BOILER) (ECON.)	Btu/lb	531.5
18	ENTHALPY OF REHEATED STEAM R.H. INLET	Btu/lb	1253
19	ENTHALPY OF REHEATED STEAM R. H. OUTLET	Btu/lb	1520
20	HEAT ABS/LB OF STEAM (ITEM 16 – ITEM 17)	Btu/lb	886.5
21	HEAT ABS/LB R.H. STEAM (ITEM 19 – ITEM 18)	Btu/lb	267
22	DRY REFUSE (ASH PIT + FLY ASH) PER LB AS FIRED FUEL	lb/lb	0
23	Btu PER LB IN REFUSE (WEIGHTED AVERAGE)	Btu/lb	0
24	CARBON BURNED PER LB AS FIRED FUEL	lb/lb	.8426
25	DRY GAS PER LB AS FIRED FUEL BURNED	lb/lb	16.6

HOURLY QUANTITIES

26	ACTUAL WATER EVAPORATED	lb/hr	5039000
27	REHEAT STEAM FLOW	lb/hr	4178500
28	RATE OF FUEL FIRING (AS FIRED wt)	lb/hr	323700
29	TOTAL HEAT INPUT $\frac{\text{Item 28} \times \text{Item 41}}{1000}$	kB/hr	6129000
30	HEAT OUTPUT IN BLOW-DOWN WATER	kB/hr	108500
31	TOTAL HEAT OUTPUT $\frac{(\text{Item 26} \times \text{Item 20}) + (\text{Item 27} \times \text{Item 21})}{1000}$ + Item 30	kB/hr	5637000

FLUE GAS ANAL. (BOILER)(ECON) (AIR HTR) OUTLET

32	CO_2	% VOL	12.8
33	O_2	% VOL	3.7
34	CO	% VOL	0.0
35	N_2 (BY DIFFERENCE)	% VOL	83.5
36	EXCESS AIR	%	19.8

FUEL DATA

	COAL AS FIRED PROX. ANALYSIS	% wt		OIL	
37	MOISTURE		51	FLASH POINT F*	
38	VOL MATTER		52	Sp. Gravity Deg. API*	
39	FIXED CARBON		53	VISCOSITY AT SSU* BURNER SSF	
40	ASH		44	TOTAL HYDROGEN % wt	
	TOTAL		41	Btu per lb	18932
41	Btu per lb AS FIRED				
42	ASH SOFT TEMP.* ASTM METHOD			GAS	% VOL
	COAL OR OIL AS FIRED ULTIMATE ANALYSIS		54	CO	
43	CARBON	84.26	55	CH_4 METHANE	
44	HYDROGEN	12.11	56	C_2H_2 ACETYLENE	
45	OXYGEN	2.3	57	C_2H_4 ETHYLENE	
46	NITROGEN	0.23	58	C_2H_6 ETHANE	
47	SULPHUR	0.25	59	H_2S	
40	ASH	0.05	60	CO_2	
37	MOISTURE	0.8	61	H_2 HYDROGEN	
	TOTAL	100.0		TOTAL	
	COAL PULVERIZATION			TOTAL HYDROGEN % wt	
48	GRINDABILITY INDEX*		62	DENSITY 68 F ATM. PRESS.	
49	FINENESS % THRU 50 M*		63	Btu PER CU FT	
50	FINENESS % THRU 200 M*		41	Btu PER LB	

64 INPUT-OUTPUT EFFICIENCY OF UNIT % $\frac{\text{ITEM 31} \times 100}{\text{ITEM 29}}$ 92%

	HEAT LOSS EFFICIENCY	Btu/lb A. F. FUEL	% of A. F. FUEL
65	HEAT LOSS DUE TO DRY GAS	713	3.76
66	HEAT LOSS DUE TO MOISTURE IN FUEL	8.9	.05
67	HEAT LOSS DUE TO H_2O FROM COMB. OF H_2	1217	6.43
68	HEAT LOSS DUE TO COMBUST. IN REFUSE		0
69	HEAT LOSS DUE TO RADIATION		0.21
70	UNMEASURED LOSSES		1.5
71	TOTAL		11.95
72	EFFICIENCY = (100 – Item 71)		88.05

* Not Required for Efficiency Testing

† For Point of Measurement See Par. 7.2.8.1-PTC 4.1-1964

SUMMARY SHEET

ASME TEST FORM
FOR ABBREVIATED EFFICIENCY TEST

PTC 4.1-a (1964)

TEST NO. FGR BOILER NO. 7 DATE 9/15/78
OWNER OF PLANT PG&E LOCATION
TEST CONDUCTED BY OBJECTIVE OF TEST DURATION
BOILER, MAKE & TYPE RATED CAPACITY
STOKER, TYPE & SIZE
PULVERIZER, TYPE & SIZE BURNER, TYPE & SIZE
FUEL USED MINE COUNTY STATE SIZE AS FIRED

PRESSURES & TEMPERATURES

1	STEAM PRESSURE IN BOILER DRUM	psia	
2	STEAM PRESSURE AT S. H. OUTLET	psia	3719
3	STEAM PRESSURE AT R. H. INLET	psia	658
4	STEAM PRESSURE AT R. H. OUTLET	psia	631
5	STEAM TEMPERATURE AT S. H. OUTLET	F	1012
6	STEAM TEMPERATURE AT R. H. INLET	F	553
7	STEAM TEMPERATURE AT R. H. OUTLET	F	1012
8	WATER TEMP. ENTERING (ECON.) (BOILER)	F	538
9	STEAM QUALITY % MOISTURE OR P. P. M.		
10	AIR TEMP. AROUND BOILER (AMBIENT)	F	63
11	TEMP. AIR FOR COMBUSTION (This is Reference Temperature) †	F	78
12	TEMPERATURE OF FUEL	F	127
13	GAS TEMP. LEAVING (Boiler) (Econ.) (Air Htr.)	F	262
14	GAS TEMP. ENTERING AH (If conditions to be corrected to guarantee)	F	

UNIT QUANTITIES

15	ENTHALPY OF SAT. LIQUID (TOTAL HEAT)	Btu/lb	534
16	ENTHALPY OF (SATURATED) (SUPERHEATED) STM.	Btu/lb	1423
17	ENTHALPY OF SAT. FEED TO (BOILER) (ECON.)	Btu/lb	534
18	ENTHALPY OF REHEATED STEAM R. H. INLET	Btu/lb	1251
19	ENTHALPY OF REHEATED STEAM R. H. OUTLET	Btu/lb	1523
20	HEAT ABS/LB OF STEAM (ITEM 16 – ITEM 17)	Btu/lb	889
21	HEAT ABS/LB R. H. STEAM (ITEM 19 – ITEM 18)	Btu/lb	272
22	DRY REFUSE (ASH PIT + FLY ASH) PER LB AS FIRED FUEL	lb/lb	0
23	Btu PER LB IN REFUSE (WEIGHTED AVERAGE)	Btu/lb	0
24	CARBON BURNED PER LB AS FIRED FUEL	lb/lb	0.8444
25	DRY GAS PER LB AS FIRED FUEL BURNED	lb/lb	15.8

HOURLY QUANTITIES

26	ACTUAL WATER EVAPORATED	lb/hr	4981000
27	REHEAT STEAM FLOW	lb/hr	4152000
28	RATE OF FUEL FIRING (AS FIRED wt)	lb/hr	319700
29	TOTAL HEAT INPUT $\frac{\text{(Item 28} \times \text{Item 41)}}{1000}$	kB/hr	5949000
30	HEAT OUTPUT IN BLOW-DOWN WATER	kB/hr	102800
31	TOTAL HEAT OUTPUT $\frac{\text{(Item 26} \times \text{Item 20)} + \text{(Item 27} \times \text{Item 21)}}{1000}$ + Item 30	kB/hr	5558000

FLUE GAS ANAL. (BOILER) (ECON) (AIR HTR) OUTLET

32	CO_2	% VOL	13.5
33	O_2	% VOL	2.8
34	CO	% VOL	0.0
35	N_2 (BY DIFFERENCE)	% VOL	83.7
36	EXCESS AIR	%	14.3

FUEL DATA

	COAL AS FIRED PROX. ANALYSIS	% wt
37	MOISTURE	
38	VOL MATTER	
39	FIXED CARBON	
40	ASH	
	TOTAL	
41	Btu per lb AS FIRED	
42	ASH SOFT TEMP.* ASTM METHOD	

	COAL OR OIL AS FIRED ULTIMATE ANALYSIS	
43	CARBON	84.44
44	HYDROGEN	11.97
45	OXYGEN	2.01
46	NITROGEN	0.27
47	SULPHUR	0.31
40	ASH	0.05
37	MOISTURE	0.95
	TOTAL	100.0

	COAL PULVERIZATION	
48	GRINDABILITY INDEX*	
49	FINENESS % THRU 50 M*	
50	FINENESS % THRU 200 M*	

	OIL	
51	FLASH POINT F*	
52	Sp. Gravity Deg. API*	
53	VISCOSITY AT SSU* BURNER SSF	
44	TOTAL HYDROGEN % wt	
41	Btu per lb	18611

	GAS	% VOL
54	CO	
55	CH_4 METHANE	
56	C_2H_2 ACETYLENE	
57	C_2H_4 ETHYLENE	
58	C_2H_6 ETHANE	
59	H_2S	
60	CO_2	
61	H_2 HYDROGEN	
	TOTAL	
	TOTAL HYDROGEN % wt	
62	DENSITY 68 F ATM. PRESS.	
63	Btu PER CU FT	
41	Btu PER LB	

64 INPUT-OUTPUT EFFICIENCY OF UNIT % $\frac{\text{ITEM 31} \times 100}{\text{ITEM 29}}$ 93.4%

	HEAT LOSS EFFICIENCY	Btu/lb A. F. FUEL	% of A. F. FUEL
65	HEAT LOSS DUE TO DRY GAS	698	3.75
66	HEAT LOSS DUE TO MOISTURE IN FUEL	10.7	0.06
67	HEAT LOSS DUE TO H_2O FROM COMB. OF H_2	1208	6.5
68	HEAT LOSS DUE TO COMBUST. IN REFUSE		
69	HEAT LOSS DUE TO RADIATION		0.21
70	UNMEASURED LOSSES		1.5
71	TOTAL		12.02
72	EFFICIENCY = (100 – Item 71)		87.98

*Not Required for Efficiency Testing

† For Point of Measurement See Par. 7.2.8.1-PTC 4.1-1964

APPENDIX B
TRACE ELEMENT ANALYTICAL METHODS

The following paragraphs present the trace element analysis procedures used to analyze Moss Landing samples. The fuel oil/crude oil mixture was analyzed in the following manner:

> Proximate and Ultimate analyses were performed and the specific gravity determined. Boron was determined photometrically using curcumin reagent, followed by ashing and fusing with sodium carbonate. The remaining trace elements were determined on the Parr bomb residue digestion by various methods; uranium by fluorimetry; mercury by cold vapor flameless atomic absorption; arsenic and selenium by hydride generation; antimony, tellurium, tin, vanadium, and zirconium by electrothermal atomization; and the remaining fifteen trace elements by flame atomic absorption spectrophotometry.

Trace elements in the XAD-2 resin were analyzed by the following method:

> Boron was determined photometrically using curcumin reagent, following ashing and fusing with sodium carbonate. The remaining trace elements were determined on the Parr bomb residue digestion by various methods; uranium by fluorimetry; mercury by cold vapor flameless atomic absorption; arsenic and selenium by hydride generation; antimony, tellurium, tin, vanadium, and zirconium by electrothermal atomization; and the remaining fifteen trace elements by flame atomic absorption spectrophotometry.

Several analyses were run on the flyash samples taken from the filter in the SASS train. Carbon and hydrogen in the flyash were analyzed by the following method:

> Portions of the filters with attached flyash were weighed and analyzed for carbon and hydrogen on a per gram of filter and flyash basis. Percent values were then calculated on an ash only basis.

Trace elements in the flyash were determined by the following methods:

> The filters and accompanying flyash were digested with aqua-regia, filtered, and analyzed for trace elements. Boron was determined photometrically using curcumin reagent; uranium was determined

fluorimetrically; mercury by cold vapor flameless atomic absorption; arsenic and selenium by hydride generation; antimony, tellurium, tin, vanadium, and zirconium by electrothermal atomization; and the remaining fifteen trace elements by flame atomic absorption spectrophotometry.

Trace elements in the first impinger solution were analyzed by the following methods:

A measured volume of each solution was digested to fumes with nitric and sulfuric acids, and re-diluted to volume. The digested samples were analyzed for trace elements. Boron was determined photometrically using curcumin reagent; uranium was determined fluorometrically; mercury by cold vapor flameless atomic absorption; arsenic and selenium by hydride generation; antimony, tellurium, tin, vanadium, and zirconium by electrothermal atomization; and the remaining fifteen trace elements by flame atomic absorption spectrophotometry.

Trace elements in the second and third impinger solutions were analyzed by the following method:

The samples were analyzed for antimony by electrothermal atomization atomic absorption, arsenic by hydride generation, and mercury by cold vapor flameless atomic absorption.

APPENDIX C
TRACE ELEMENT CONCENTRATIONS

Symbols appearing in the tables:

DSCM	Dry Standard Cubic Meter
KG	Kilogram
MCG	Microgram
PPM	Part per million by weight
SEC	Second
<	Less than
*	Sample not analyzed for the particular element/or ionic specie
N	Sample not analyzed
-	Concentration in the sample is less than the concentration in the blank

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OIL FIRED UTILITY BOILER

TRACE ELEMENT CONCENTRATION - (PPM) - FUEL

TRACE ELEMENT	TEST CONDITION		
CATION	BASELINE	LOW NOX	FG RECIRC
ANTIMONY	< .300	< .400	< .400
ARSENIC	< 1.00	< 2.00	< 2.00
BARIUM	< 26.0	< 37.0	< 35.0
BERYLLIUM	< 1.00	< 2.00	< 2.00
BISMUTH	< 8.00	< 11.0	< 11.0
BORON	53.0	31.0	66.0
CADMIUM	< .500	< .700	< .700
CHROMIUM	5.00	3.00	4.00
COBALT	< 3.00	< 4.00	< 4.00
COPPER	23.0	53.0	16.0
IRON	32.0	27.0	51.0
LEAD	5.00	7.00	4.00
MANGANESE	< 1.00	< 2.00	< 2.00
MERCURY	.400-01	.300-01	.400-01
MOLYBDENUM	< 15.0	< 21.0	< 20.0
NICKEL	26.0	35.0	20.0
SELENIUM	< .200	1.60	< .200
TELLURIUM	< .200	< .300	< .300
THALLIUM	< 5.00	< 6.00	< 6.00
TIN	< .200	< .300	1.60
TITANIUM	< 7.00	< 10.0	< 9.00
URANIUM	1.00	1.00	< 1.00
VANADIUM	4.20	5.30	1.80
ZINC	1.60	2.00	3.90
ZIRCONIUM	< 13.0	< 18.0	< 17.0
ANION			
CHLORIDE	* .000	* .000	* .000
FLUORIDE	* .000	* .000	* .000
CYANIDE	* .000	* .000	* .000
NITRATE	* .000	* .000	* .000
SULFATE	* .000	* .000	* .000
AMMONIUM	* .000	* .000	* .000

OIL FIRED UTILITY BOILER

TRACE ELEMENT CONCENTRATION - (PPM) - UNIT OUTLET
FILTER DUST

TRACE ELEMENT			TEST CONDITION			
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY		15.4		13.4		23.4
ARSENIC		129.		159.		129.
BARIUM		.255+04		.193+04		.187+04
BERYLLIUM	<	5.00	<	5.00	<	3.00
BISMUTH	<	27.0	<	27.0	<	21.0
BORON		.102+04		.109+04		640.
CADMIUM	<	2.00	<	2.00	<	1.00
CHROMIUM		372.		262.		262.
COBALT		827.		747.		807.
COPPER		427.		337.		327.
IRON		2.29		1.93		1.96
LEAD		1.53		1.13		1.17
MANGANESE		347.		317.		287.
MERCURY		2.46		1.86		1.06
MOLYBDENUM		148.		148.		158.
NICKEL		1.49		1.34		1.51
SELENIUM		3.00		7.00		2.00
TELLURIUM	<	.600	<	.600	<	.600
THALLIUM	<	15.0	<	15.0	<	11.0
TIN	<	.600	<	.600	<	.600
TITANIUM	<	23.0	<	23.0	<	17.0
URANIUM		3.00		3.00	<	1.00
VANADIUM		.752+04		.712+04		.762+04
ZINC		.336+04		.264+04		.258+04
ZIRCONIUM	<	42.0	<	42.0	-	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

OIL FIRED UTILITY BOILER

TRACE ELEMENT CONCENTRATION - (PPM) - UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT	TEST CONDITION		
CATION	BASELINE	LOW NOX	FG RECIRC
ANTIMONY	- .000	< 1.00	- .000
ARSENIC	- .000	< 5.00	- .000
BARIUM	- .000	< 110.	- .000
BERYLLIUM	- .000	< 6.00	- .000
BISMUTH	- .000	< 36.0	- .000
BORON	850.	450.	.451+04
CADMIUM	7.00	< 2.00	- .000
CHROMIUM	1.00	5.00	1.00
COBALT	- .000	< 14.0	- .000
COPPER	5.00	115.	255.
IRON	- .000	6.00	18.0
LEAD	- .000	< 14.0	- .000
MANGANESE	- .000	< 7.00	< 36.0
MERCURY	- .000	- .000	- .000
MOLYBDENUM	- .000	< 68.0	- .000
NICKEL	- .000	240.	810.
SELENIUM	- .000	- .000	- .000
TELLURIUM	- .000	< 1.20	- .000
THALLIUM	- .000	< 20.0	- .000
TIN	- .000	16.0	- .000
TITANIUM	- .000	< 30.0	- .000
URANIUM	- .000	< 3.00	- .000
VANADIUM	- .000	< 2.00	- .000
ZINC	- .000	- .000	- .000
ZIRCONIUM	- .000	< 57.0	- .000
ANION			
CHLORIDE	* .000	* .000	* .000
FLUORIDE	* .000	* .000	* .000
CYANIDE	* .000	* .000	* .000
NITRATE	* .000	* .000	* .000
SULFATE	* .000	* .000	* .000
AMMONIUM	* .000	* .000	* .000

OIL FIRED UTILITY BOILER

TRACE ELEMENT CONCENTRATION - (PPM) - UNIT OUTLET IMPINGER

TRACE ELEMENT	TEST CONDITION		
CATION	BASELINE	LOW NOX	FG RECIRC
ANTIMONY	- .000	- .000	- .000
ARSENIC	- .000	- .000	- .000
BARIUM	- .000	- .000	- .000
BERYLLIUM	- .000	- .000	- .000
BISMUTH	- .000	- .000	- .000
BORON	1.00	1.00	.400
CADMIUM	- .000	- .000	- .000
CHROMIUM	1.90	1.10	1.70
COBALT	.700-01	.200-01	.500-01
COPPER	.400-01	.800-01	.800-01
IRON	13.0	7.00	9.00
LEAD	- .000	- .000	- .000
MANGANESE	.690	.560	.510
MERCURY	- .000	- .000	- .000
MOLYBDENUM	- .000	- .000	- .000
NICKEL	2.06	1.56	2.16
SELENIUM	- .000	- .000	- .000
TELLURIUM	- .000	- .000	- .000
THALLIUM	- .000	- .000	- .000
TIN	- .000	- .000	- .000
TITANIUM	- .000	- .000	- .000
URANIUM	- .000	- .000	- .000
VANADIUM	- .000	- .000	- .000
ZINC	.900-01	.700-01	.900-01
ZIRCONIUM	- .000	- .000	- .000
ANION			
CHLORIDE	* .000	* .000	* .000
FLUORIDE	* .000	* .000	* .000
CYANIDE	* .000	* .000	* .000
NITRATE	* .000	* .000	* .000
SULFATE	* .000	* .000	* .000
AMMONIUM	* .000	* .000	* .000

OIL FIRED UTILITY BOILER

TRACE ELEMENT CONCENTRATION - (PPM) - UNIT OUTLET
2ND - 3RD IMPGS

TRACE ELEMENT		TEST CONDITION				
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY	-	.000	-	.000	-	.000
ARSENIC	-	.000	-	.000	-	.000
BARIUM	*	.000	*	.000	*	.000
BERYLLIUM	*	.000	*	.000	*	.000
BISMUTH	*	.000	*	.000	*	.000
BORON	*	.000	*	.000	*	.000
CADMIUM	*	.000	*	.000	*	.000
CHROMIUM	*	.000	*	.000	*	.000
COBALT	*	.000	*	.000	*	.000
COPPER	*	.000	*	.000	*	.000
IRON	*	.000	*	.000	*	.000
LEAD	*	.000	*	.000	*	.000
MANGANESE	*	.000	*	.000	*	.000
MERCURY	-	.000	-	.000	-	.000
MOLYBDENUM	*	.000	*	.000	*	.000
NICKEL	*	.000	*	.000	*	.000
SELENIUM	*	.000	*	.000	*	.000
TELLURIUM	*	.000	*	.000	*	.000
THALLIUM	*	.000	*	.000	*	.000
TIN	*	.000	*	.000	*	.000
TITANIUM	*	.000	*	.000	*	.000
URANIUM	*	.000	*	.000	*	.000
VANADIUM	*	.000	*	.000	*	.000
ZINC	*	.000	*	.000	*	.000
ZIRCONIUM	*	.000	*	.000	*	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

APPENDIX D

TRACE ELEMENT FLOWRATES

Symbols appearing in the tables:

DSCM	Dry Standard Cubic Meter
KG	Kilogram
MCG	Microgram
PPM	Part per million by weight
SEC	Second
<	Less than
*	Sample not analyzed for the particular element/or ionic specie
N	Sample not analyzed
-	Concentration in the sample is less than the concentration in the blank

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APPENDIX D-1

TRACE ELEMENT FLOWRATE

(kilograms per second)

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (KG/SEC) -FUEL

TRACE ELEMENT	TEST CONDITION					
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY	<	.122-04	<	.163-04	<	.161-04
ARSENIC	<	.407-04	<	.816-04	<	.806-04
BARIUM	<	.106-02	<	.151-02	<	.141-02
BERYLLIUM	<	.407-04	<	.816-04	<	.806-04
BISMUTH	<	.326-03	<	.449-03	<	.443-03
BORON		.216-02		.127-02		.266-02
CADMIUM	<	.204-04	<	.286-04	<	.282-04
CHROMIUM		.204-03		.122-03		.161-03
COBALT	<	.122-03	<	.163-03	<	.161-03
COPPER		.937-03		.216-02		.645-03
IRON		.130-02		.110-02		.206-02
LEAD		.204-03		.286-03		.161-03
MANGANESE	<	.407-04	<	.816-04	<	.806-04
MERCURY		.163-05		.122-05		.161-05
MOLYBDENUM	<	.611-03	<	.857-03	<	.806-03
NICKEL		.106-02		.143-02		.806-03
SELENIUM	<	.815-05		.653-04	<	.806-05
TELLURIUM	<	.815-05	<	.122-04	<	.121-04
THALLIUM	<	.204-03	<	.245-03	<	.242-03
TIN	<	.815-05	<	.122-04		.645-04
TITANIUM	<	.285-03	<	.408-03	<	.363-03
URANIUM		.407-04		.408-04	<	.403-04
VANADIUM		.171-03		.216-03		.726-04
ZINC		.652-04		.816-04		.157-03
ZIRCONIUM	<	.530-03	<	.735-03	<	.685-03
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

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OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (KG/SEC) -UNIT OUTLET
FILTER DUST

TRACE ELEMENT		TEST CONDITION	
CATION	BASELINE	LOW NOX	FG RECIRC
ANTIMONY	.587-06	.394-06	.898-06
ARSENIC	.492-05	.468-05	.495-05
BARIUM	.974-04	.569-04	.720-04
BERYLLIUM	< .191-06	< .147-06	< .115-06
BISMUTH	< .103-05	< .795-06	< .806-06
BORON	.389-04	.321-04	.246-04
CADMIUM	< .763-07	< .589-07	< .384-07
CHROMIUM	.142-04	.771-05	.101-04
COBALT	.315-04	.220-04	.310-04
COPPER	.163-04	.992-05	.126-04
IRON	.873-07	.568-07	.753-07
LEAD	.584-07	.333-07	.449-07
MANGANESE	.132-04	.933-05	.110-04
MERCURY	.938-07	.547-07	.407-07
MOLYBDENUM	.565-05	.436-05	.607-05
NICKEL	.568-07	.394-07	.580-07
SELENIUM	.114-06	.206-06	.768-07
TELLURIUM	< .229-07	< .177-07	< .230-07
THALLIUM	< .572-06	< .441-06	< .422-06
TIN	< .229-07	< .177-07	< .230-07
TITANIUM	< .877-06	< .677-06	< .653-06
URANIUM	.114-06	.883-07	< .384-07
VANADIUM	.287-03	.209-03	.293-03
ZINC	.128-03	.776-04	.990-04
ZIRCONIUM	< .160-05	< .124-05	- .000
ANION			
CHLORIDE	* .000	* .000	* .000
FLUORIDE	* .000	* .000	* .000
CYANIDE	* .000	* .000	* .000
NITRATE	* .000	* .000	* .000
SULFATE	* .000	* .000	* .000
AMMONIUM	* .000	* .000	* .000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (KG/SEC) -UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT		TEST CONDITION	
CATION	BASELINE	LOW NOX	FG RECIRC
ANTIMONY	- .000	< .310-05	- .000
ARSENIC	- .000	< .155-04	- .000
BARIUM	- .000	< .341-03	- .000
BERYLLIUM	- .000	< .186-04	- .000
BISMUTH	- .000	< .112-03	- .000
BORON	.286-02	.140-02	.154-01
CADMIUM	.235-04	< .620-05	- .000
CHROMIUM	.336-05	.155-04	.341-05
COBALT	- .000	< .434-04	- .000
COPPER	.168-04	.357-03	.869-03
IRON	- .000	.186-04	.614-04
LEAD	- .000	< .434-04	- .000
MANGANESE	- .000	< .217-04	< .123-03
MERCURY	- .000	- .000	- .000
MOLYBDENUM	- .000	< .211-03	- .000
NICKEL	- .000	.744-03	.276-02
SELENIUM	- .000	- .000	- .000
TELLURIUM	- .000	< .372-05	- .000
THALLIUM	- .000	< .620-04	- .000
TIN	- .000	.496-04	- .000
TITANIUM	- .000	< .930-04	- .000
URANIUM	- .000	< .930-05	- .000
VANADIUM	- .000	< .620-05	- .000
ZINC	- .000	- .000	- .000
ZIRCONIUM	- .000	< .177-03	- .000
ANION			
CHLORIDE	* .000	* .000	* .000
FLUORIDE	* .000	* .000	* .000
CYANIDE	* .000	* .000	* .000
NITRATE	* .000	* .000	* .000
SULFATE	* .000	* .000	* .000
AMMONIUM	* .000	* .000	* .000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (KG/SEC) -UNIT OUTLET
IMPINGER

TRACE ELEMENT		TEST CONDITION				
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY	-	.000	-	.000	-	.000
ARSENIC	-	.000	-	.000	-	.000
BARIUM	-	.000	-	.000	-	.000
BERYLLIUM	-	.000	-	.000	-	.000
BISMUTH	-	.000	-	.000	-	.000
BORON		.254-04		.340-04		.183-04
CADMIUM	-	.000	-	.000	-	.000
CHROMIUM		.483-04		.374-04		.779-04
COBALT		.178-05		.679-06		.229-05
COPPER		.102-05		.272-05		.367-05
IRON		.331-03		.238-03		.412-03
LEAD	-	.000	-	.000	-	.000
MANGANESE		.175-04		.190-04		.234-04
MERCURY	-	.000	-	.000	-	.000
MOLYBDENUM	-	.000	-	.000	-	.000
NICKEL		.524-04		.530-04		.990-04
SELENIUM	-	.000	-	.000	-	.000
TELLURIUM	-	.000	-	.000	-	.000
THALLIUM	-	.000	-	.000	-	.000
TIN	-	.000	-	.000	-	.000
TITANIUM	-	.000	-	.000	-	.000
URANIUM	-	.000	-	.000	-	.000
VANADIUM	-	.000	-	.000	-	.000
ZINC		.229-05		.238-05		.412-05
ZIRCONIUM	-	.000	-	.000	-	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (KG/SEC) -UNIT OUTLET
2ND - 3RD IMPGS

TRACE ELEMENT		TEST CONDITION	
CATION	BASELINE	LOW NOX	FG RECIRC
ANTIMONY	- .000	- .000	- .000
ARSENIC	- .000	- .000	- .000
BARIUM	* .000	* .000	* .000
BERYLLIUM	* .000	* .000	* .000
BISMUTH	* .000	* .000	* .000
BORON	* .000	* .000	* .000
CADMIUM	* .000	* .000	* .000
CHROMIUM	* .000	* .000	* .000
COBALT	* .000	* .000	* .000
COPPER	* .000	* .000	* .000
IRON	* .000	* .000	* .000
LEAD	* .000	* .000	* .000
MANGANESE	* .000	* .000	* .000
MERCURY	- .000	- .000	- .000
MOLYBDENUM	* .000	* .000	* .000
NICKEL	* .000	* .000	* .000
SELENIUM	* .000	* .000	* .000
TELLURIUM	* .000	* .000	* .000
THALLIUM	* .000	* .000	* .000
TIN	* .000	* .000	* .000
TITANIUM	* .000	* .000	* .000
URANIUM	* .000	* .000	* .000
VANADIUM	* .000	* .000	* .000
ZINC	* .000	* .000	* .000
ZIRCONIUM	* .000	* .000	* .000
ANION			
CHLORIDE	* .000	* .000	* .000
FLUORIDE	* .000	* .000	* .000
CYANIDE	* .000	* .000	* .000
NITRATE	* .000	* .000	* .000
SULFATE	* .000	* .000	* .000
AMMONIUM	* .000	* .000	* .000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (KG/SEC) -UNIT OUTLET

TRACE ELEMENT		TEST CONDITION				
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY		.587-06		.349-05		.898-06
ARSENIC		.492-05		.202-04		.495-05
BARIUM		.974-04		.398-03		.720-04
BERYLLIUM	<	.191-06	<	.187-04	<	.115-06
BISMUTH	<	.103-05	<	.112-03	<	.806-06
BORON		.292-02		.146-02		.154-01
CADMIUM	<	.236-04	<	.626-05	<	.384-07
CHROMIUM		.659-04		.606-04		.914-04
COBALT		.333-04		.661-04		.335-04
COPPER		.341-04		.369-03		.885-03
IRON		.331-03		.256-03		.474-03
LEAD		.584-07		.434-04		.449-07
MANGANESE		.308-04		.501-04		.157-03
MERCURY		.938-07		.547-07		.407-07
MOLYBDENUM		.565-05		.215-03		.607-05
NICKEL		.524-04		.797-03		.286-02
SELENIUM		.114-06		.206-06		.768-07
TELLURIUM	<	.229-07	<	.374-05	<	.230-07
THALLIUM	<	.572-06	<	.624-04	<	.422-06
TIN	<	.229-07	<	.496-04	<	.230-07
TITANIUM	<	.877-06	<	.937-04	<	.655-06
URANIUM		.114-06		.939-05	<	.384-07
VANADIUM		.287-03		.216-03		.295-03
ZINC		.130-03		.800-04		.105-03
ZIRCONIUM	<	.160-05	<	.178-03	-	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

APPENDIX D-2

TRACE ELEMENT FLOWRATES

(micrograms per joule)

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/JOULE) -FUEL

TRACE ELEMENT				TEST CONDITION		
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY	<	.744-05	<	.927-05	<	.878-05
ARSENIC	<	.248-04	<	.464-04	<	.439-04
BARIUM	<	.645-03	<	.857-03	<	.768-03
BERYLLIUM	<	.248-04	<	.464-04	<	.439-04
BISMUTH	<	.198-03	<	.255-03	<	.241-03
BORON		.131-02		.718-03		.145-02
CADMIUM	<	.124-04	<	.162-04	<	.154-04
CHROMIUM		.124-03		.695-04		.878-04
COBALT	<	.744-04	<	.927-04	<	.878-04
COPPER		.571-03		.123-02		.351-03
IRON		.794-03		.626-03		.112-02
LEAD		.124-03		.162-03		.878-04
MANGANESE	<	.248-04	<	.464-04	<	.439-04
MERCURY		.992-06		.695-06		.878-06
MOLYBDENUM	<	.372-03	<	.487-03	<	.439-03
NICKEL		.645-03		.811-03		.439-03
SELENIUM	<	.496-05		.371-04	<	.439-05
TELLURIUM	<	.496-05	<	.695-05	<	.658-05
THALLIUM	<	.124-03	<	.139-03	<	.132-03
TIN	<	.496-05	<	.695-05		.351-04
TITANIUM	<	.174-03	<	.232-03	<	.198-03
URANIUM		.248-04		.232-04	<	.219-04
VANADIUM		.104-03		.123-03		.395-04
ZINC		.397-04		.464-04		.856-04
ZIRCONIUM	<	.323-03	<	.417-03	<	.373-03
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

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OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/JOULE) -UNIT OUTLET
FILTER DUST

TRACE ELEMENT		TEST CONDITION				
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY		.358-06		.224-06		.490-06
ARSENIC		.300-05		.266-05		.270-05
BARIUM		.594-04		.323-04		.392-04
BERYLLIUM	<	.116-06	<	.836-07	<	.628-07
BISMUTH	<	.628-06	<	.452-06	<	.439-06
BORON		.237-04		.182-04		.134-04
CADMIUM	<	.465-07	<	.334-07	<	.209-07
CHROMIUM		.865-05		.438-05		.548-05
COBALT		.192-04		.125-04		.169-04
COPPER		.993-05		.564-05		.684-05
IRON		.533-07		.323-07		.410-07
LEAD		.356-07		.189-07		.245-07
MANGANESE		.807-05		.530-05		.600-05
MERCURY		.572-07		.311-07		.222-07
MOLYBDENUM		.344-05		.248-05		.331-05
NICKEL		.346-07		.224-07		.316-07
SELENIUM		.698-07		.117-06		.418-07
TELLURIUM	<	.140-07	<	.100-07	<	.126-07
THALLIUM	<	.349-06	<	.251-06	<	.230-06
TIN	<	.140-07	<	.100-07	<	.126-07
TITANIUM	<	.535-06	<	.385-06	<	.356-06
URANIUM		.698-07		.502-07	<	.209-07
VANADIUM		.175-03		.119-03		.159-03
ZINC		.781-04		.441-04		.539-04
ZIRCONIUM	<	.977-06	<	.702-06	-	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/JOULE) -UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT		TEST CONDITION				
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY	-	.000	<	.176-05	-	.000
ARSENIC	-	.000	<	.881-05	-	.000
BARIUM	-	.000	<	.194-03	-	.000
BERYLLIUM	-	.000	<	.106-04	-	.000
BISMUTH	-	.000	<	.634-04	-	.000
BORON		.174-02		.793-03		.838-02
CADMIUM		.143-04	<	.352-05	-	.000
CHROMIUM		.205-05		.881-05		.186-05
COBALT	-	.000	<	.247-04	-	.000
COPPER		.102-04		.203-03		.474-03
IRON	-	.000		.106-04		.334-04
LEAD	-	.000	<	.247-04	-	.000
MANGANESE	-	.000	<	.123-04	<	.669-04
MERCURY	-	.000	-	.000	-	.000
MOLYBDENUM	-	.000	<	.120-03	-	.000
NICKEL	-	.000		.423-03		.150-02
SELENIUM	-	.000	-	.000	-	.000
TELLURIUM	-	.000	<	.211-05	-	.000
THALLIUM	-	.000	<	.352-04	-	.000
TIN	-	.000		.282-04	-	.000
TITANIUM	-	.000	<	.529-04	-	.000
URANIUM	-	.000	<	.529-05	-	.000
VANADIUM	-	.000	<	.352-05	-	.000
ZINC	-	.000	-	.000	-	.000
ZIRCONIUM	-	.000	<	.100-03	-	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/JOULE) -UNIT OUTLET
IMPINGER

TRACE ELEMENT	TEST CONDITION					
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY	-	.000	-	.000	-	.000
ARSENIC	-	.000	-	.000	-	.000
BARIUM	-	.000	-	.000	-	.000
BERYLLIUM	-	.000	-	.000	-	.000
BISMUTH	-	.000	-	.000	-	.000
BORON		.155-04		.193-04		.999-05
CADMIUM	-	.000	-	.000	-	.000
CHROMIUM		.295-04		.212-04		.424-04
COBALT		.109-05		.386-06		.125-05
COPPER		.620-06		.154-05		.200-05
IRON		.202-03		.135-03		.225-03
LEAD	-	.000	-	.000	-	.000
MANGANESE		.107-04		.108-04		.127-04
MERCURY	-	.000	-	.000	-	.000
MOLYBDENUM	-	.000	-	.000	-	.000
NICKEL		.319-04		.301-04		.539-04
SELENIUM	-	.000	-	.000	-	.000
TELLURIUM	-	.000	-	.000	-	.000
THALLIUM	-	.000	-	.000	-	.000
TIN	-	.000	-	.000	-	.000
TITANIUM	-	.000	-	.000	-	.000
URANIUM	-	.000	-	.000	-	.000
VANADIUM	-	.000	-	.000	-	.000
ZINC		.140-05		.135-05		.225-05
ZIRCONIUM	-	.000	-	.000	-	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/JOULE) -UNIT OUTLET
2ND - 3RD IMPGS

TRACE ELEMENT	TEST CONDITION		
CATION	BASELINE	LOW NOX	FG RECIRC
ANTIMONY	- .000	- .000	- .000
ARSENIC	- .000	- .000	- .000
BARIUM	* .000	* .000	* .000
BERYLLIUM	* .000	* .000	* .000
BISMUTH	* .000	* .000	* .000
BORON	* .000	* .000	* .000
CADMIUM	* .000	* .000	* .000
CHROMIUM	* .000	* .000	* .000
COBALT	* .000	* .000	* .000
COPPER	* .000	* .000	* .000
IRON	* .000	* .000	* .000
LEAD	* .000	* .000	* .000
MANGANESE	* .000	* .000	* .000
MERCURY	- .000	- .000	- .000
MOLYBDENUM	* .000	* .000	* .000
NICKEL	* .000	* .000	* .000
SELENIUM	* .000	* .000	* .000
TELLURIUM	* .000	* .000	* .000
THALLIUM	* .000	* .000	* .000
TIN	* .000	* .000	* .000
TITANIUM	* .000	* .000	* .000
URANIUM	* .000	* .000	* .000
VANADIUM	* .000	* .000	* .000
ZINC	* .000	* .000	* .000
ZIRCONIUM	* .000	* .000	* .000
ANION			
CHLORIDE	* .000	* .000	* .000
FLUORIDE	* .000	* .000	* .000
CYANIDE	* .000	* .000	* .000
NITRATE	* .000	* .000	* .000
SULFATE	* .000	* .000	* .000
AMMONIUM	* .000	* .000	* .000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/JOULE) -UNIT OUTLET

TRACE ELEMENT	TEST CONDITION					
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY		.358-06		.199-05		.490-06
ARSENIC		.300-05		.115-04		.270-05
BARIUM		.594-04		.226-03		.392-04
BERYLLIUM	<	.116-06	<	.107-04	<	.628-07
BISMUTH	<	.628-06	<	.639-04	<	.439-06
BORON		.178-02		.830-03		.840-02
CADMIUM	<	.144-04	<	.356-05	<	.209-07
CHROMIUM		.402-04		.344-04		.498-04
COBALT		.203-04		.375-04		.181-04
COPPER		.208-04		.210-03		.482-03
IRON		.202-03		.146-03		.258-03
LEAD		.356-07		.247-04		.245-07
MANGANESE		.188-04		.284-04		.856-04
MERCURY		.572-07		.311-07		.222-07
MOLYBDENUM		.344-05		.122-03		.331-05
NICKEL		.320-04		.453-03		.156-02
SELENIUM		.698-07		.117-06		.418-07
TELLURIUM	<	.140-07	<	.212-05	<	.126-07
THALLIUM	<	.349-06	<	.355-04	<	.230-06
TIN	<	.140-07	<	.282-04	<	.126-07
TITANIUM	<	.535-06	<	.532-04	<	.356-06
URANIUM		.698-07		.534-05	<	.209-07
VANADIUM		.175-03		.123-03		.159-03
ZINC		.795-04		.455-04		.562-04
ZIRCONIUM	<	.977-06	<	.101-03	-	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

APPENDIX D-3
TRACE ELEMENT FLOWRATES
(micrograms per dry standard cubic meter)

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/DSCM) -UNIT OUTLET
FILTER DUST

TRACE ELEMENT	TEST CONDITION		
CATION	BASELINE	LOW NOX	F6 RECIRC
ANTIMONY	1.02	.641	1.52
ARSENIC	8.54	7.61	8.36
BARIUM	169.	92.5	121.
BERYLLIUM	< .331	< .239	< .194
BISMUTH	< 1.79	< 1.29	< 1.36
BORON	67.5	52.2	41.5
CADMIUM	< .132	< .957-01	< .648-01
CHROMIUM	24.6	12.5	17.0
COBALT	54.7	35.7	52.3
COPPER	28.3	16.1	21.2
IRON	.152	.924-01	.127
LEAD	.101	.541-01	.758-01
MANGANESE	23.0	15.2	18.6
MERCURY	.163	.890-01	.687-01
MOLYBDENUM	9.80	7.08	10.2
NICKEL	.986-01	.641-01	.979-01
SELENIUM	.199	.335	.130
TELLURIUM	< .397-01	< .287-01	< .389-01
THALLIUM	< .993	< .718	< .713
TIN	< .397-01	< .287-01	< .389-01
TITANIUM	< 1.52	< 1.10	< 1.10
URANIUM	.199	.144	< .648-01
VANADIUM	498.	341.	494.
ZINC	222.	126.	167.
ZIRCONIUM	< 2.78	< 2.01	- .000
ANION			
CHLORIDE	* .000	* .000	* .000
FLUORIDE	* .000	* .000	* .000
CYANIDE	* .000	* .000	* .000
NITRATE	* .000	* .000	* .000
SULFATE	* .000	* .000	* .000
AMMONIUM	* .000	* .000	* .000

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OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/DSCM) -UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT		TEST CONDITION				
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY	-	.000	<	5.04	-	.000
ARSENIC	-	.000	<	25.2	-	.000
BARIUM	-	.000	<	554.	-	.000
BERYLLIUM	-	.000	<	30.2	-	.000
BISMUTH	-	.000	<	181.	-	.000
BORON		.495+04		.227+04		.260+05
CADMIUM		40.8	<	10.1	-	.000
CHROMIUM		5.83		25.2		5.75
COBALT	-	.000	<	70.6	-	.000
COPPER		29.1		580.		.147+04
IRON	-	.000		30.2		104.
LEAD	-	.000	<	70.6	-	.000
MANGANESE	-	.000	<	35.3	<	207.
MERCURY	-	.000	-	.000	-	.000
MOLYBDENUM	-	.000	<	343.	-	.000
NICKEL	-	.000		.121+04		.466+04
SELENIUM	-	.000	-	.000	-	.000
TELLURIUM	-	.000	<	6.05	-	.000
THALLIUM	-	.000	<	101.	-	.000
TIN	-	.000		80.7	-	.000
TITANIUM	-	.000	<	151.	-	.000
URANIUM	-	.000	<	15.1	-	.000
VANADIUM	-	.000	<	10.1	-	.000
ZINC	-	.000	-	.000	-	.000
ZIRCONIUM	-	.000	<	287.	-	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/DSCM) -UNIT OUTLET
IMPINGER

TRACE ELEMENT				TEST CONDITION		
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY	-	.000	-	.000	-	.000
ARSENIC	-	.000	-	.000	-	.000
BARIUM	-	.000	-	.000	-	.000
BERYLLIUM	-	.000	-	.000	-	.000
BISMUTH	-	.000	-	.000	-	.000
BORON		44.1		55.2		30.9
CADMIUM	-	.000	-	.000	-	.000
CHROMIUM		83.8		60.8		131.
COBALT		3.09		1.10		3.87
COPPER		1.76		4.42		6.19
IRON		574.		387.		696.
LEAD	-	.000	-	.000	-	.000
MANGANESE		30.4		30.9		39.4
MERCURY	-	.000	-	.000	-	.000
MOLYBDENUM	-	.000	-	.000	-	.000
NICKEL		90.9		86.2		167.
SELENIUM	-	.000	-	.000	-	.000
TELLURIUM	-	.000	-	.000	-	.000
THALLIUM	-	.000	-	.000	-	.000
TIN	-	.000	-	.000	-	.000
TITANIUM	-	.000	-	.000	-	.000
URANIUM	-	.000	-	.000	-	.000
VANADIUM	-	.000	-	.000	-	.000
ZINC		3.97		3.87		6.96
ZIRCONIUM	-	.000	-	.000	-	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/DSCM) -UNIT OUTLET
2ND - 3RD IMPGS

TRACE ELEMENT			TEST CONDITION			
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY	-	.000	-	.000	-	.000
ARSENIC	-	.000	-	.000	-	.000
BARIUM	*	.000	*	.000	*	.000
BERYLLIUM	*	.000	*	.000	*	.000
BISMUTH	*	.000	*	.000	*	.000
BORON	*	.000	*	.000	*	.000
CADMIUM	*	.000	*	.000	*	.000
CHROMIUM	*	.000	*	.000	*	.000
COBALT	*	.000	*	.000	*	.000
COPPER	*	.000	*	.000	*	.000
IRON	*	.000	*	.000	*	.000
LEAD	*	.000	*	.000	*	.000
MANGANESE	*	.000	*	.000	*	.000
MERCURY	-	.000	-	.000	-	.000
MOLYBDENUM	*	.000	*	.000	*	.000
NICKEL	*	.000	*	.000	*	.000
SELENIUM	*	.000	*	.000	*	.000
TELLURIUM	*	.000	*	.000	*	.000
THALLIUM	*	.000	*	.000	*	.000
TIN	*	.000	*	.000	*	.000
TITANIUM	*	.000	*	.000	*	.000
URANIUM	*	.000	*	.000	*	.000
VANADIUM	*	.000	*	.000	*	.000
ZINC	*	.000	*	.000	*	.000
ZIRCONIUM	*	.000	*	.000	*	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

OIL FIRED UTILITY BOILER

TRACE ELEMENT ANALYSIS - (MCG/DSCM) -UNIT OUTLET

TRACE ELEMENT		TEST CONDITION				
CATION		BASELINE		LOW NOX		FG RECIRC
ANTIMONY		1.02		5.68		1.52
ARSENIC		8.54		32.8		8.36
BARIUM		169.		647.		121.
BERYLLIUM	<	.331	<	30.5	<	.194
BISMUTH	<	1.79	<	183.	<	1.36
BORON		.507+04		.238+04		.260+05
CADMIUM	<	40.9	<	10.2	<	.648-01
CHROMIUM		114.		98.5		154.
COBALT		57.8		107.		56.2
COPPER		59.2		600.		.149+04
IRON		574.		417.		800.
LEAD		.101		70.6		.758-01
MANGANESE		53.4		81.4		265.
MERCURY		.165		.890-01		.687-01
MOLYBDENUM		9.80		350.		10.2
NICKEL		91.0		.130+04		.485+04
SELENIUM		.199		.335		.130
TELLURIUM	<	.397-01	<	6.08	<	.389-01
THALLIUM	<	.995	<	102.	<	.715
TIN	<	.397-01	<	80.7	<	.389-01
TITANIUM	<	1.52	<	152.	<	1.10
URANIUM		.199		15.3	<	.648-01
VANADIUM		498.		351.		494.
ZINC		226.		130.		174.
ZIRCONIUM	<	2.78	<	289.	-	.000
ANION						
CHLORIDE	*	.000	*	.000	*	.000
FLUORIDE	*	.000	*	.000	*	.000
CYANIDE	*	.000	*	.000	*	.000
NITRATE	*	.000	*	.000	*	.000
SULFATE	*	.000	*	.000	*	.000
AMMONIUM	*	.000	*	.000	*	.000

APPENDIX E
MOSS LANDING ORGANIC ANALYSES METHODS AND RESULTS

PROJECT 7245 -- MOSS LANDING

1. INTRODUCTION

Samples collected at Moss Landing, California over a 3-day period during November 1979 were analyzed using Level 1 environmental assessment methodologies. In addition all XAD extracts were analyzed by GC/MS. The baseline sample was further subjected to LC separation.

2. METHODS

GCMS and LRMS determinations were conducted using a Finnigan Model 4000 computerized gas chromatograph/mass spectrometer.

GCMS determinations were conducted on a 6-foot, 1/4 inch O.D. column of 1 percent SP2250 on 100/120 mesh Supelcoport interfaced via an all-glass jet separator to the mass spectrometer. A 2-microliter sample was injected onto the column at 60^oC and the column was temperature programmed to 265^oC at 8^oC per minute. After an initial 1.5 minutes, the mass range, 45 to 475 a.m.u. was continuously scanned at 2.0-second intervals.

LRMS determinations were initiated by evaporating a 10-microliter sample in a glass capillary and inserting the capillary into the source region of the mass spectrometer using the solid probe inlet of the instrument. The filament of the mass spectrometer was turned on and the mass range of 45 to 475 a.m.u. was scanned continuously while the initially cold probe (0^oC) was slowly heated to 250^oC.

The mass spectrometer was calibrated with decafluorotriphenylphosphine (DFTPP). To assure sensitivity for polycyclic aromatics a standard mixture containing 40 nanograms of each species asterisked in Table E-1 was analyzed. This standard run also provided response factors which were used to calculate the quantitative data in Table E-2.

3. CALCULATIONS

Samples were spiked with the quantitation standard at the level of 20 micrograms d_{10}-anthracene per milliliter of sample. The amount of a particular compound in the sample was calculated using its response factor relative to d_{10}-anthracene. This value is corrected for dilution factors and for method blank contributions. Finally, sample compound values were adjusted to reflect stack emissions (XAD-2 extracts) or process sample emissions (bottom ash, flyash).

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TABLE E-1. COMPOUNDS SOUGHT IN MOSS LANDING ORGANICS SAMPLES

4-bromophenyl phenyl ether	*
bis(2-chloroisopropyl) ether	*
bis(2-chloroethoxy) methane	*
hexachlorobutadiene	*
hexachlorocyclopentadiene	*
isophorone	*
naphthalene	*
nitrobenzene	*
N-nitrosodiphenylamine	*
N-nitrosodi-n-propylamine	*
bis(2-ethylhexyl) phthalate	*
butyl benzyl phthalate	*
di-n-butyl phthalate	*
di-n-octyl phthalate	*
diethyl phthalate	*
dimethyl phthalate	*
benzo(a)anthrazene	*
benzo(a)pyrene	*
3,4-benzofluoranthene	*
benzo(k)fluoranthene	*
chrysene	*
acenaphthylene	*
anthracene	*
benzo(ghi)perylene	*
fluorene	*
phenanthrene	*
dibenzo(a,h)anthracene	*
indeno(1,2,3-cd)pyrene	*
pyrene	*
2,3,7,8-tetrachlorodibenzo-p-dioxin	
acenaphthene	*
benzidine	*
1,2,3-trichlorobenzene	*
hexachlorobenzene	*
hexachloroethane	*
bis(2-chloroethyl)ether	*
2-chloronaphthalene	*
1,2-dichlorobenzene	*
1,3-dichlorobenzene	*
1,4-dichlorobenzene	*
3,3'-dichlorobenzidine	*
2,4-dinitrotoluene	*
2,6-dinitrotoluene	*
1,2-diphenylhydrazine (as azobenzene)	*
fluoranthene	*
4-chlorophenyl phenyl ether	*
anthanthrene	
benzo(e)pyrene	
dibenzo(a,H)pyrene	
dibenzo(a,i)pyrene	
dibenzo(c,g)carbozole	
7,12 dimethyl benz(a)anthracene	
3-methyl cholanthrene	
perylene	

*Compound in calibration standard

TABLE E-2. ORGANICS DETECTED IN MOSS LANDING XAD EXTRACTS

Compound	Concentration $\mu g/m^3$ [a]		
	BOOS/FGR	Baseline	FGR
Dichlorobenzene	0.1	--	--
Fluorene	0.1	--	--
Phenanthrene/anthracene	0.7	0.1	0.2
Fluoranthene	0.1	--	0.1
Pyrene	0.2	--	--
Bis (2-ethythexyl) phthalate	120.0		5.0
Chrysene/benz(a)anthracene	0.1	--	--

[a] Based on sample volume:

BOOS/FGR	27.3 m^3 sampled
Baseline	27.9 m^3 sampled
FGR	28.6 m^3 sampled

Sample Calculation:

The XAD-2 extract for the BOOS/FGR test was concentrated to 10 ml. A 3.5 ml aliquot was concentrated to 1 ml and spiked with 20 micrograms of d_{10}-anthracene. GCMS analysis of this sample indicated the presence of 6.8 micrograms of phenanthrene/anthracene (these isomers coelute under our gas chromatographic conditions). The BOOS/FGR sample volume was 27.3 m^3. Therefore the stack gas contained:

$$\frac{6.8\,(\mu g) \times \frac{10\text{ (mls total extract)}}{3.5\text{ (mls used for analysis)}} \times 0.001\,\left(\frac{mg}{\mu g}\right)}{27.3\,(m^3)} = 0.0007\,\frac{mg}{m^3}$$

4. GCMS RESULTS

The raw mass spectral data were screened for the compounds listed in Table E-1. In addition, background corrected mass spectra were obtained for all large peaks, and these were compared to the 26,000 spectra in the NBS library of mass spectra of common organics. Results, corrected for blank concentrations, are shown in Table E-2.

The major species seen in XAD-2 extracts are polynuclear aromatic compounds and phthalate contaminants. The phthalates, especially bis(2-ethylhexyl), are present in the samples at higher levels than seen in laboratory blanks. This may be due to contamination.

After liquid chromatographic separation, baseline fractions 2 and 3 were analyzed for polynuclear aromatics. No polynuclear aromatics could be detected to a limit of 50 ng/m^3.

5. LOW RESOLUTION MASS SPECTROMETRY

The following samples were analyzed by LRMS:

Baseline LC fractions 4 and 5
LC fractions 6 and 7

No species could be detected in any LRMS analysis above background.

The infrared analysis reports for Moss Landing XAD-2 extracts and liquid chromatographic fractions from these XAD-2 extracts are presented on the following pages.

The infrared analysis reports for Moss Landing XAD-2 extracts and liquid chromatographic fractions from these XAD-2 extracts are presented in the following pages.

IR ANALYSIS REPORT

Contractor Acurex Corporation, E/E Division

Sample Site Moss Landing **Sample Acquisition Date**

Type of Source Residual Oil Fired Utility Boiler

Test Number I-9-17 **Sample ID Number** ML-2-X, LC-1

Sample Description Liquid Chromatography Fraction 1, XAD-2 extract Day 2

Responsible Analyst J. B. Stevens **Date Analyzed** January 9, 1979

Calculations and Report Reviewed By R. Milligan **Report Date**

Instrument Perkin Elmer **Sample Cell Type** Salt Plate

Utilized Max/Min Signal Intensity Values

Observations Identical to blank

Wave Number (cm^{-1})	Intensity	Assignment	Comments
2940, 2920			
2840	S	Aliphatic CH	same pattern as blank
1460	M	CH_3/alkane bending	same pattern as blank
1370	W	CH_3/alkane bending	

IR ANALYSIS REPORT

Contractor Acurex Corporation, E/E Division

Sample Site Moss Landing **Sample Acquisition Date**

Type of Source Residual Oil Fired Utility Boiler

Test Number I-9-18 **Sample ID Number** ML-2-X LC2

Sample Description LC Fraction 2 XAD-2 extract Day 2

Responsible Analyst J. B. Stevens **Date Analyzed** January 9, 1979

Calculations and Report Reviewed By R. J. Milligan **Report Date**

Instrument Perkin Elmer **Sample Cell Type**

Utilized Max/Min Signal Intensity Values

Observations Nothing visible in either the spectrum or the blank

Wave Number (cm^{-1})	Intensity	Assignment Comments

IR ANALYSIS REPORT

Contractor Acurex Corporation, E/E Division

Sample Site Moss Landing **Sample Acquisition Date**

Type of Source Residual Oil Fired Utility Boiler

Test Number I-10-2 **Sample ID Number** ML-2-X LC-3

Sample Description LC Fraction 3 XAD-2 extract Day 2

Responsible Analyst J. B. Stevens **Date Analyzed** January 10, 1979

Calculations and Report Reviewed By R. J. Milligan **Report Date**

Instrument Perkin Elmer **Sample Cell Type**

Utilized Max/Min Signal Intensity Values

Observations This is a major constituent of the XAD-2 extract spectrum for Day 2 It appears to be an aliphatic ether of very simple structure

Wave Number (cm^{-1})	Intensity	Assignment	Comments
2960, 2900	M	Aliphatic C-H	
1440, 1410			
1400 (sh)	M	CH_3/aliphatic bending	
1255	S	C-O (ether linkage)	
1100-1000	VS	C-O-C symmetrical	
860 (sh)	M	Unassigned	
795	S	Bending mode	
700	M	Unassigned	
680	M	Unassigned	
650	M	Unassigned	

IR ANALYSIS REPORT

Contractor Acurex Corporation, E/E Division

Sample Site Moss Landing **Sample Acquisition Date**

Type of Source Residual Oil Fired Utility Boiler

Test Number I-10-3 **Sample ID Number** ML-2-X LC-4

Sample Description LC Fraction 4 XAD-2 extract Day 2

Responsible Analyst J. B. Stevens **Date Analyzed** January 10, 1979

Calculations and Report Reviewed By R. J. Milligan **Report Date**

Instrument Perkin Elmer **Sample Cell Type**

Utilized Max/Min Signal Intensity Values

Observations The blank indicates the elution of OH, either alcohol or (disturbingly) a carboxylic acid. The sample shows no sign of OH and is much like LC-3 with increase in CH (both in size and number of bands) and aliphatic bending

Wave Number (cm^{-1})	Intensity	Assignment	Comments
2960, 2900	M	Aliphatic C-H	
2840			
2495	W	Possible C H	
1940, 2040	W	Possible	
1440, 1405	MM		
1400(sh)1370( )	MW	Aliphatic bending	
1255	S	C-O ether	
1000-1100	VS	C-O-C symmetric	
860	M	Unassigned	
800	S	Bending mode?	
700	M	Unassigned	
680	M	Unassigned	
650	M	Unassigned	

indicating ether beginning to be contaminated by a second substance with unknown functional group (conjecture imide/anhydride or cyano or both).

IR ANALYSIS REPORT

Contractor Acurex Corporation, E/E Division

Sample Site Moss Landing **Sample Acquisition Date**

Type of Source Residual Oil Fired Utility Boiler

Test Number I-10-4 **Sample ID Number** ML-2-X LC-5

Sample Description LC Fraction 5 XAD-2 extract Day 2

Responsible Analyst J. B. Stevens **Date Analyzed** January 10, 1979

Calculations and Report Reviewed By R. J. Milligan **Report Date**

Instrument Perkin Elmer **Sample Cell Type**

Utilized Max/Min Signal Intensity Values

Observations Identical to LC-4 but at lower intensity

Wave Number (cm^{-1})	Intensity	Assignment	Comments
2960, 2920(sh)			
2900, 2840	M	Aliphatic C-H	
1440, 1410			
1400(sh)	M	Aliphatic bending	
1255	S	C-O	
1000-1100	VS	C-O-C ether symmetric	
860	M	Unassigned	
800	S	Bending mode?	Broad
700	M	Unassigned	
680	M	Unassigned	
655	M	Unassigned	

IR ANALYSIS REPORT

Contractor Acurex Corporation, E/E Division

Sample Site Moss Landing **Sample Acquisition Date**

Type of Source Residual Oil Fired Utility Boiler

Test Number I-10-5 **Sample ID Number** ML-2-X, LC-6

Sample Description LC Function 6 XAD-2 extract Day 2

Responsible Analyst J. B. Stevens **Date Analyzed** January 10, 1979

Calculations and Report Reviewed By R. J. Milligan **Report Date**

Instrument Perkin Elmer **Sample Cell Type**

Utilized Max/Min Signal Intensity Values

Observations Still some ether left but major compound is a carboxylic acid blank too weak to be of much use

Wave Number (cm^{-1})	Intensity	Assignment	Comments
3600-3100	M	-OH hydroxyl	all or partial in blank
2950, 2910	S	C-H aliphatic	part in blank
2860, 2850			
1730	S	Carboxyl	all or part in blank
1600	W	Aromatic C=C	
1580	W	Unassigned	
1450, 1420	M	Aliphatic bending	
1370			
1255	M	C-O of ether in broader C-O of carboxylic acid	
1240-1280	M		
1200	W(sh)	Unassigned	
1010-1120		Distorted sym C-O-C of ether	
860	W	Unassigned	
800	M	Unassigned	
740	W	Unassigned	
710-680	M	Unassigned	

IR ANALYSIS REPORT

Contractor Acurex Corporation, E/E Division

Sample Site Moss Landing **Sample Acquisition Date**

Type of Source Residual Oil Fired Utility Boiler

Test Number I-10-6 **Sample ID Number** ML-2-X, LC-7

Sample Description LC Fraction 7 XAD-2 extract Day 2

Responsible Analyst J. B. Stevens **Date Analyzed** January 10, 1979

Calculations and Report Reviewed By R. J. Milligan **Report Date**

Instrument Perkin Elmer **Sample Cell Type**

Utilized Max/Min Signal Intensity Values

Observations Carboxylic acid (fairly weak spectrum) very similar to blank for LC-6 (blank for LC-7 shows nothing)

Wave Number (cm^{-1})	Intensity	Assignment	Comments
3600-3100	M	Hydroxyl	broad
2960, 2910			
2840	S	Aliphatic CH	
1730	S	Carboxyl	
1430, 1370	M	Aliphatic C-C-H bending	
1230-1260	S	C-O	broad
1090, 1010	S	C-O stretching possibility some due to ether	
790	S	Unassigned	
730	S	Unassigned	

IR ANALYSIS REPORT

Contractor Acurex Corporation, E/E Division

Sample Site Moss Landing **Sample Acquisition Date** ____

Type of Source Residual Oil Fired Utility Boiler

Test Number I-9-7 **Sample ID Number** ML-1-X

Sample Description Moss Landing XAD-2 extract Day 1

Responsible Analyst Bruce Stevens **Date Analyzed** January 9, 1979

Calculations and Report Reviewed By R. Milligan **Report Date** ____

Instrument Perkin Elmer **Sample Cell Type** Salt Plate

Utilized Max/Min Signal Intensity Values ____

Observations The blank contains more hydroxyl than the sample indicating that what hydroxyl is present may be due to XAD-2

Wave Number (cm^{-1})	Intensity	Assignment	Comments
2950,2920,2840	S	Aliphatic CH	some to most XAD-2
1740	S	Carboxyl	some to most XAD-2
1600	W	Aromatic C=C	some to most XAD-2
3600-2800	M	Hydroxyl	all XAD-2
1580	W	Unassigned	
1450	M	Methyl/aliphatic bend	some to most XAD-2
1380	M	Methyl/aliphatic bend	some to most XAD-2
1285-1260	M	C-O-	portion XAD-2
1115	W	Unassigned	some to most XAD-2
1065	W	Unassigned	
1020	W	Unassigned	some to most XAD-2
800	M	Unassigned	some to most XAD-2
740	W	Unassigned	
700	W	Unassigned	

IR ANALYSIS REPORT

Contractor Acurex Corporation, E/E Division

Sample Site Moss Landing **Sample Acquisition Date**

Type of Source Residual Oil Fired Utility Boilers

Test Number I-10-21 **Sample ID Number** ML-2-XAD-2

Sample Description Moss Landing XAD-2 Extract Day 2

Responsible Analyst J. B. Stevens **Date Analyzed** January 10, 1979

Calculations and Report Reviewed By R. Milligan **Report Date**

Instrument **Sample Cell Type** Salt Plate

Utilized Max/Min Signal Intensity Values

Observations Unlike the blank, the spectrum contains very little OH

Wave Number (cm^{-1})	Intensity	Assignment	Comments
3760, 3680	W	Unassigned	
2960,2920,2900			
2860, 2840	S	Aliphatic C-H	most or all in blank
2490	W	Possible C≡N	
1940	M		
1730	S	Carboxyl	most or all in blank
1600	W	Aromatic C=C	most or all in blank
1440, 1410			
1400, 1370	M	Methyl, aliphatic bending	some in blank
1250-1260	S	C-O	broad some in blank
900-1200	VS		too strong to assign
720-900	VS		too strong to assign
650-700	S	Denotes substitution	

IR ANALYSIS REPORT

Contractor Acurex Corporation, E/E Division

Sample Site Moss Landing **Sample Acquisition Date**

Type of Source Residual Oil Fired Utility Boiler

Test Number I-10-23 **Sample ID Number** ML-3-X

Sample Description Moss Landing XAD-2 Extract Day 3

Responsible Analyst J. B. Stevens **Date Analyzed** January 10, 1979

Calculations and Report Reviewed By R. Milligan **Report Date**

Instrument Perkin Elmer **Sample Cell Type** Salt Plate

Utilized Max/Min Signal Intensity Values

Observations Looks very much like ML-2-XAD-2 except at lower concentration

Wave Number (cm^{-1})	Intensity	Assignment	Comments
2950,2920,2840	S	Aliphatic C-H	Most or all in blank
2490	W	Possible C≡N	
1940/2040	M	Imide or anhydride (overtone)	
1720	S	Carboxyl	most or all in blank
1600	W	Aromatic C=C	most or all in blank
1440, 1410	M		some in blank
1400(sh),1370			
1255	S	C-O	
930-1210	VS		Too strong to differentiate and assign
860(sh)	M	Unassigned	Denotes substituting bending
790-800	S	Unassigned	
695, 680	M	Unassigned	
655			

May 4, 1977

Level 1 Organic Analysis Procedure Modification

Pilot Studies Protocol

Reasons for this Modification:

The original Level 1 Organic Analysis Procedure, as specified in the June 1976 Procedures Manual, was designed in a manner which provided qualitative compound class identification and quantitative (gravimetric) data for those components of a sample that are retained when an organic sample extract is evaporated to dryness. For more volatile sample components, only quantitative information (quantities of material in defined boiling point ranges) was to be obtained. It was implicitly assumed that all compound with boiling points ≥ ca. 220°C (C_{13} and higher normal hydrocarbon range) would be retained and carried through the LC-IR-LRMS procedure, while those boiling below 220°C (C_{12} and lower normal hydrocarbons down to C_7*) might be lost during sample evaporation to dryness.

New experimental data have shown that:

1. The range of material lost when the sample is evaporated to dryness for the gravimetric analysis and preparation of the LC sample is somewhat higher than anticipated: It is probably only C_{16} and higher (rather than C_{13} and higher) hydrocarbons that are retained. The C_{16} n-alkane boiling point is about 275°C.

2. Many of the compounds which are considered to be of concern in environmental assessment as a whole (not just Level 1) are in the boiling point range that would correspond to loss prior to LC, according to present procedures. Thus, no compound class information would be available from Level 1 to indicate the possible presence or to confirm the absence of significant amounts of these materials.

* C_1 - C_6 are to be done by on-site GC.

A revised procedure for Level 1 has been devised and subjected to limited experimental validation. The principal feature of this procedure, compared to the original, is that the organic extract is not evaporated to dryness prior to the LC and/or LRMS analyses. Two new sample handling steps are required:

- A quantitative assay procedure, TCO (total chromatographable organics) to complement the gravimetric analysis, and give quantitative data on C_7-C_{16} range materials.

- A solvent exchange step to transfer the sample from a CH_2Cl_2 extract to a non-polar solvent and allow lower boiling material (> C7) to go through LC and subsequent steps.

A new flow diagram is shown in Figure 1. The two new procedures are described on the following pages.

The total mass data for extracted samples is now taken as the sum of the value determined from the TCO and gravimetric assay. (TCO + GRAV)

Note that the C7 - C12 GC assay is now not required.

Both qualitative and quantitative data are expected to be obtained by this scheme for all materials boiling above the C_7 paraffin.

All other provisions, criteria and instructions of the Procedures Manual apply except for the noted changes.

TCO

Analyze a 1 μℓ aliquot of solution by GC using a flame ionization detector. A 6 ft. x 1/8 in O.D. column of 10% OV-101 on 100/120 mesh Supelcoport has been used successfully for this analysis. Other silicon phases (OV-1, etc.) may work as well, but a 10% loading is recommended. The GC should be operated isothermally at about 30°C - or room temperature - for 5 minutes after sample injection and then programmed at approximately 20°C per minute to 250°C and held at 250°C as long as necessary for complete elution of sample.

Integrator should be set to begin integration at a time intermediate between the hexane (C_6) and heptane (C_7) peak maxima i.e. $C_{6.5}$) and terminate at the peak maxima of the heptadecane (C_{17}) peak, as determined from calibration standards. In this manner the integrated area will cover material in the boiling range of C7-C16.

Calibration should be done with a mixture containing a homologous series of hydrocarbons from C_7 to C_{16}. Standards should be prepared to cover the concentration range to be studied.

Solvent Exchange:

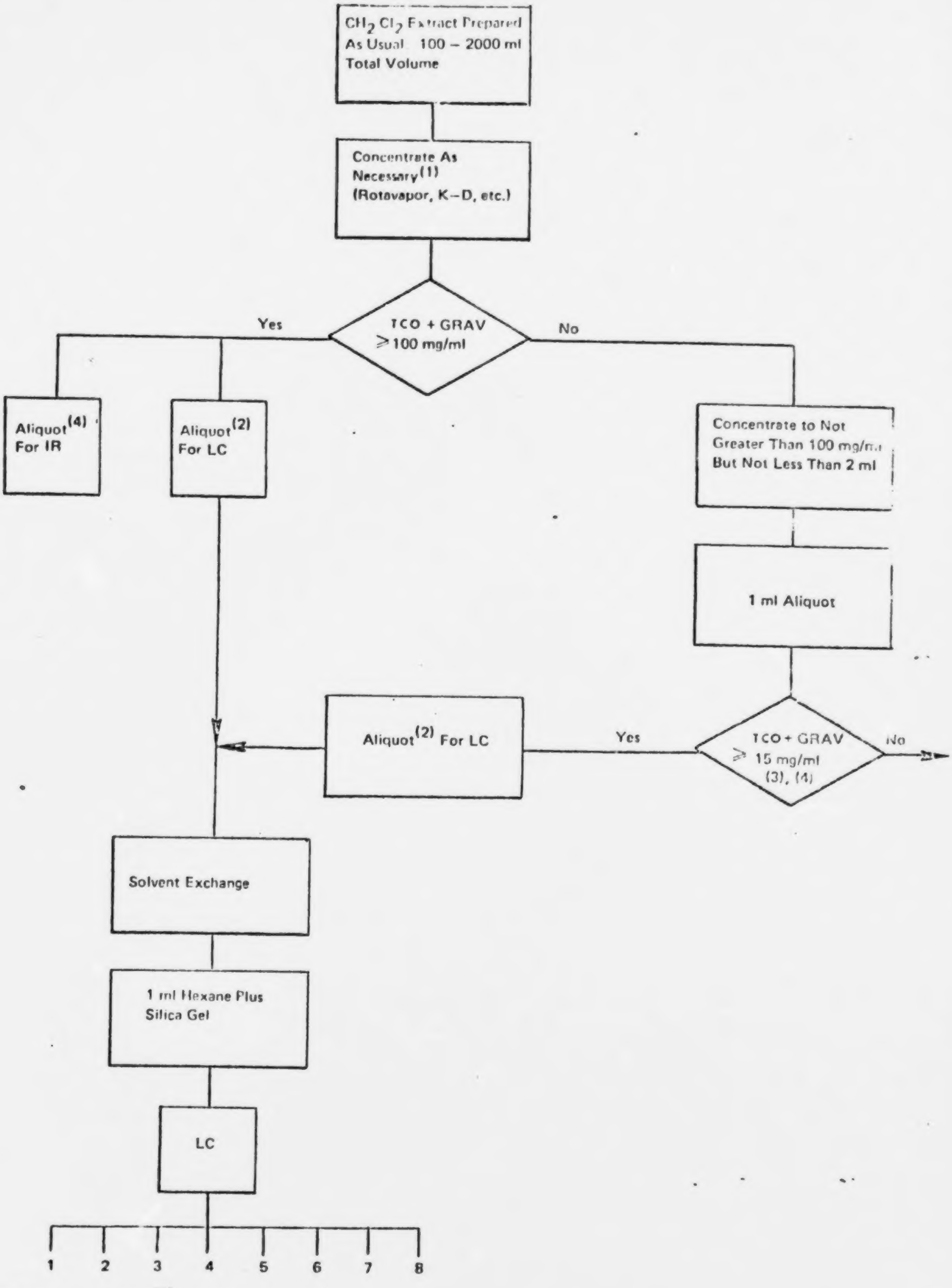
Place 1 - 5 mℓ of CH_2Cl_2 extract containing 15 - 100 mg of solute (TCO + GRAV), preferably 100 mg, in graduated centrifuge tube or K-D receiver. Add 200 mg of silica gel prepared as for the LC column. Evaporate if necessary to reduce volume to 1 mℓ.

Add 1 mℓ hexane and mix by gentle agitation. Again reduce volume to 1 mℓ by evaporation.

Add 1 mℓ more of hexane and mix. Reduce volume to 1 mℓ again.

Transfer hexane and silica gel (a Pasteur pipette works well) to top of previously prepared LC column.

Run column as directed in Manual, rinsing graduated receiver with fresh solvents as they are introduced in the elution sequence.


CH_2Cl_2 Extract Prepared As Usual. 100 – 2000 ml Total Volume
Concentrate As Necessary(1) (Rotavapor, K–D, etc.)
TCO + GRAV ≥ 100 mg/ml
Yes
No
Aliquot(4) For IR
Aliquot(2) For LC
Concentrate to Not Greater Than 100 mg/m But Not Less Than 2 ml
1 ml Aliquot
Aliquot(2) For LC
Yes
TCO + GRAV ≥ 15 mg/ml (3), (4)
No
Solvent Exchange
1 ml Hexane Plus Silica Gel
LC
1
2
3
4
5
6
7
8

Each Fraction: TCO(5) + GRAV
IR on GRAV Sample
LRMS By Batch and Probe.

See Foot notes.

Footnotes to Figure 1

(1) Stop concentration if precipitate appears and add solvent to achieve complete solution.

(2) Aliquot should be chosen to contain about 100 mg of material (TCO + GRAV) if possible, but not less than 15 mg, and be concentrated to 1 mℓ, if necessary.

(3) If TCO value (alone) at this point is less than 2 mg/mℓ, then TCO assay and batch LRMS need not be done on LC fractions.

(4) Obtain IR on GRAV assay sample.

(5) It will be necessary to neutralize fraction 8 with NaOH before TCO.

APPENDIX F
BIOASSAY METHODS AND RESULTS

APPENDIX F-1

CYTOTOXICITY EVALUATION OF LOW NO_x XAD-2 EXTRACT IN THE WI-38 ASSAY

LBI ASSAY NO. 3985

LBI SAFETY NO. 3642

CYTOTOXIC EVALUATION OF

OIL FIRED BOILER NO. 1
SASS TRAIN XAD-2 EXTRACT

IN THE
WI-38 HUMAN CELL
CYTOTOXICITY ASSAY

FINAL REPORT

SUBMITTED TO:

ACUREX CORPORATION
485 CLYDE AVE.
MOUNTAIN VIEW, CA 94042

SUBMITTED BY:

LITTON BIONETICS, INC.
5516 NICHOLSON LANE
KENSINGTON, MARYLAND 20795

LBI PROJECT NO. 20993

REPORT DATE: JUNE, 1979

Litton BIONETICS

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PREFACE

This report contains a summary of the data compiled during the evaluation of the test compound. The report is organized to present the results in a concise and easily interpretable manner. The first part contains items I-IX. Items I-IV provide sponsor and compound identification information, type of assay, and the protocol reference number. All protocol references indicate a standard procedure described in the Litton Bionetics, Inc. "Screening Program for the Identification of Potential Mutagens and Carcinogens." Item V provides the initiation and completion dates for the study, and Item VI provides identification of supervisory personnel. Item VII identifies the tables and figures containing the data used by the study director in interpreting the test results. The interpretation itself is in Item VIII. Item IX provides the conclusion and evaluation.

The second part of the report, entitled PROTOCOL, describes the materials and procedures employed in conducting the assay. This part of the report also contains evaluation criteria used by the study director, and any appendices. The evaluation criteria are included to acquaint the sponsor with the methods used to develop and analyze the test results.

All test and control results presented in this report are supported by fully documented raw data which are permanently maintained in the files of the Department of Genetics and Cell Biology or in the archives of Litton Bionetics, Inc., 5516 Nicholson Lane, Kensington Maryland, 20795.

Copies of raw data will be supplied to the sponsor upon request.

I. SPONSOR: ACUREX CORPORATION

II. MATERIAL (TEST COMPOUND): LBI ASSAY NUMBER 3985

A. Identification: Oil Fired Boiler No. 1, SASS Train XAD-2 Extract

B. Date Received: February 23, 1979

C. Physical Description: Light yellow solution in DMSO

III. TYPE OF ASSAY: WI-38 Human Cell Cytotoxicity Assay

IV. PROTOCOL NUMBER: Special Protocol

V. STUDY DATES:

A. Initiation: May 23, 1979

B. Completion: June 5, 1979

VI. SUPERVISORY PERSONNEL:

A. Study Director: Brian C. Myhr, Ph.D.

B. Laboratory Supervisor: Robert Young

VII. RESULTS:

The data are presented in Table 1 on page 3 and in Figures 1 and 2 on pages 4 and 5.

VIII. INTERPRETATION OF RESULTS:

The methylene chloride extract of the test sample on XAD-2 resin, after solvent exchange into DMSO, appeared to remain soluble in the culture medium at the highest applied concentration of 20 μl/ml. Higher concentrations could not be tested because of the introduction of greater than 2% organic solvent by volume. As shown in Table 1, 1% solvent reduced the viability index, total ATP, and total protein to about 70-80% of the untreated negative control, and 2% solvent reduced these parameters even further to about 40-50%. Thus, additional organic solvent would become highly toxic. It is known from other studies that most of this toxicity is due to DMSO rather than residual methylene chloride from the exchange process. Because of this toxicity, the effect of the test material was measured relative to the assay parameters obtained for the appropriate solvent exchanged DMSO negative control.

VIII. INTERPRETATION OF RESULTS (continued):

All five assay parameters decreased rapidly at the two highest applied concentrations (10 μl/ml and 20 μl/ml). The EC50 values ranged from 15 μl/ml for the percent viability to 8 μl/ml for the total protein content. Since the DMSO test solution corresponded to about 4785.4L of exhaust gas/ml, the EC50 range was 71.8L gas/ml to 38.3L gas/ml. These values fall within the moderate toxicity range.

IX. CONCLUSIONS:

The test material, SASS Train XAD-2 Extract, Oil Fired Boiler No. 1, is evaluated as having moderate toxicity to WI-38 human cells. The EC50 values ranged from 71.8L exhaust gas/ml for the cell viability to 38.3L exhaust gas/ml for total cellular protein content.

Submitted by:

Study Director

Brian Myhr 6/11/79

Brian Myhr, Ph.D. date
Section Chief
Mammalian Genetics
Department of Genetics
and Cell Biology

Reviewed by:

(for) 6/11/79

David J. Brusick, Ph.D. date
Director
Department of Genetics
and Cell Biology

Litton BIONETICS

TABLE 1

WI-38 HUMAN CELL CYTOTOXICITY ASSAY

Test Date: MAY 23, 1979

LBI Assay No.: 3985

Test Material Identity: Oil Fired Boiler No. 1, SASS Train XAD-2 Extract

Initial Cell Viability: 98.8%

Viable WI-38 Cells Seeded/Flask: 2.0 x 10^5

Passage Number: 27

Vehicle: DMSO/ Growth Medium

TEST RESULTS

		Average Values per Culture Flask						Expressed as Percent of Negative Control (NC)***				
Sample	Concentration†† µl/ml	Viable Cells 10^6 Units	Total Cells 10^6 Units	Cellular Protein µg	ATP 10^8 fg	ATP Per 10^6 Cells 10^8 fg	Viability %	Viability	Viability Index	Protein	ATP	ATP Per 10^6 Cells
NEGATIVE CONTROL	---	.610	.613	87	38.0	62.0	99.5	100.0	100.0	100.0	100.0	100.0
1% DMSO BLANK S.E.**		.429	.439	65	31.6	72.0	97.7	98.2	70.3	74.7	83.2	116.1
† 2% DMSO BLANK S.E.**		.317	.327	33	21.0	64.2	96.9	97.4	52.0	37.9	55.3	103.5
TEST	0.5	.456	.473	62	35.3	74.6	96.4	98.7	106.3	95.4	111.7	103.6
TEST	2.0	.454	.491	83	33.7	68.6	92.5	94.7	105.8	127.7	106.6	95.3
TEST	5.0	.379	.405	49	26.1	64.4	93.6	95.8	88.3	75.4	82.6	89.4
TEST	10.0	.223	.291	24	13.1	45.0	76.6	78.4	52.0	36.9	41.5	62.5
TEST	20.0	.005	.215	10	1.5	7.0	2.3	2.4	1.6	30.3	7.1	10.9
							*EC50 VALUES: µl/ml	15.0	10.5	8.0	9.0	12.0

Toxicity
Classification: Moderate toxicity

††pH change in culture medium: None observed

***or appropriate DMSO blank.

** 0.5 ml methylene chloride solvent exchanged to 2.0 ml DMSO

*Determined from data plots in Figures 1 and 2

†Average of 2 flasks

FIGURE 1

EC50 DETERMINATION FOR

PERCENT VIABILITY (O) AND VIABILITY INDEX (●)

OIL FIRED BOILER NO. 1

SASS TRAIN XAD-2 EXTRACT

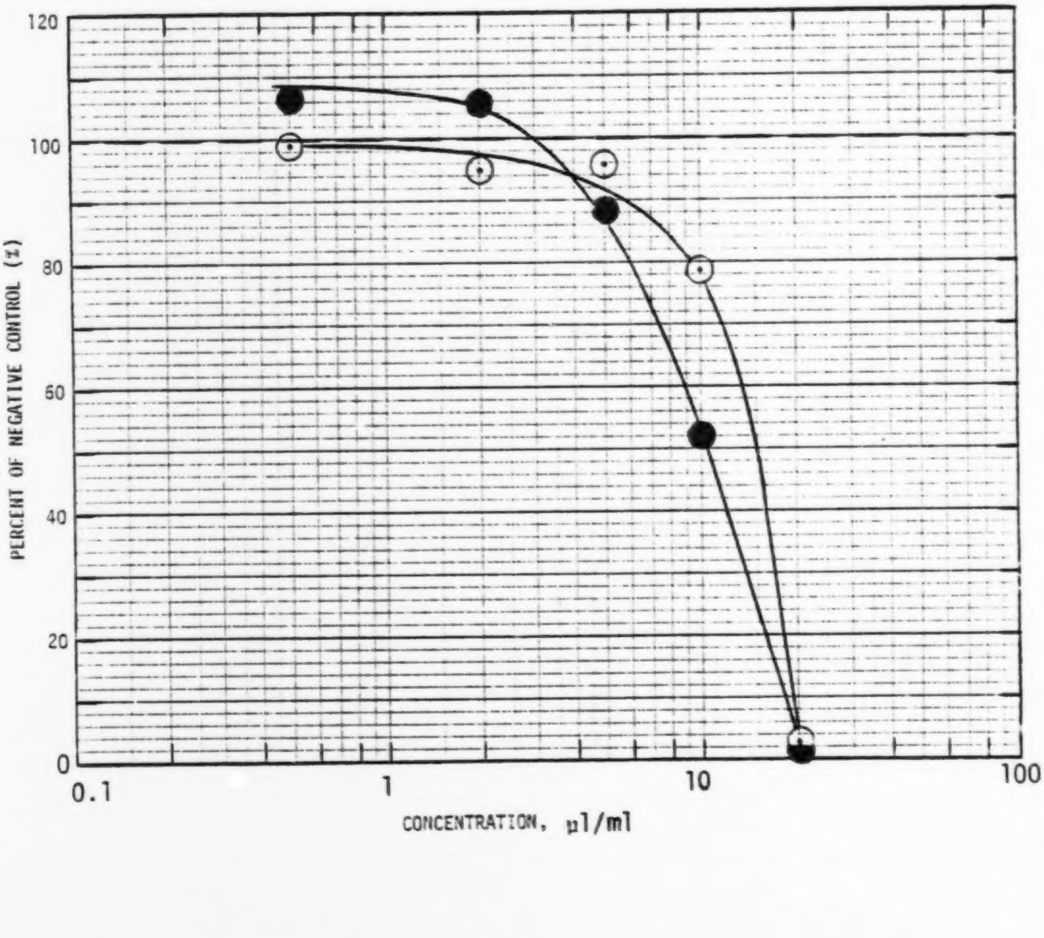


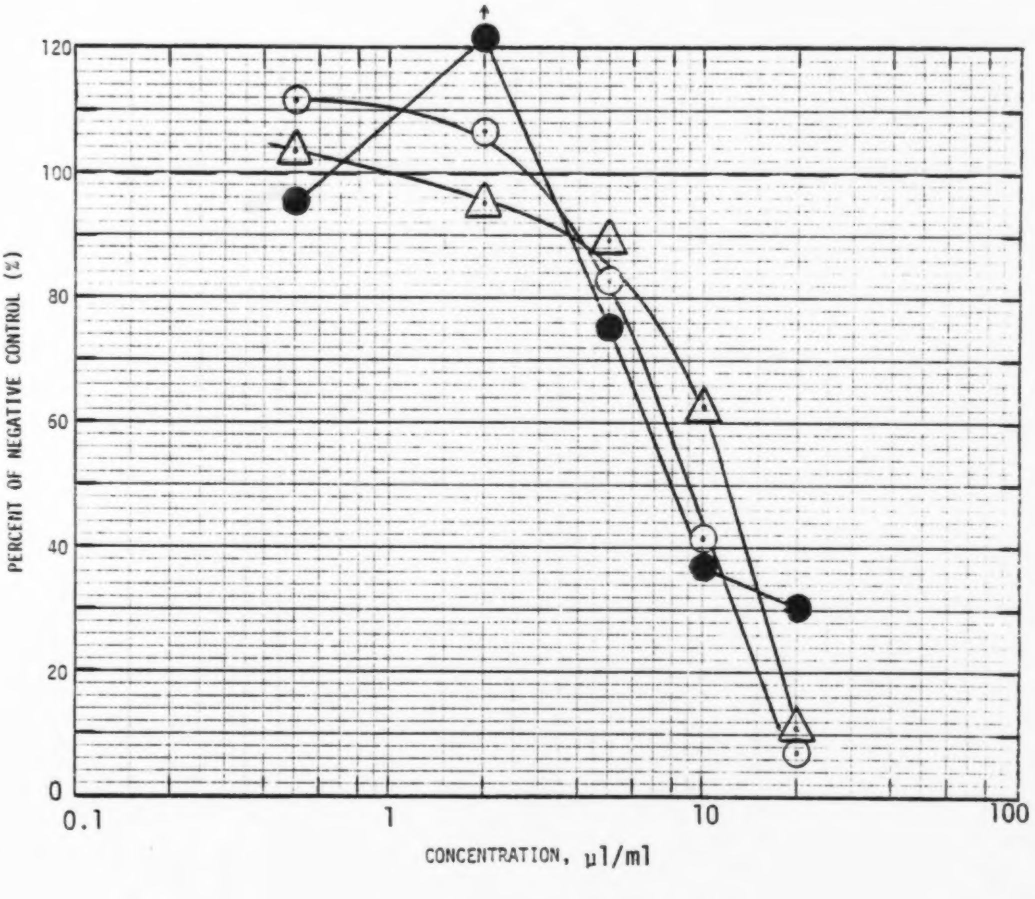
FIGURE 2

EC50 DETERMINATION FOR

PROTEIN (●), ATP (O), and ATP/10^6 CELLS (Δ)

OIL FIRED BOILER NO. 1

SASS TRAIN XAD-2 EXTRACT



ASSAY PROTOCOL

1. OBJECTIVE

The objective of this assay is to determine the concentrations of test material that reduces by 50% the number of viable cells, the cellular protein, and the ATP content after a 20 hour exposure. These concentrations are referred to as the EC50 values for each measured parameter.

2. MATERIALS

A. Indicator Cells

The indicator cells used for this study were WI-38 human embryonic lung fibroblasts obtained from Flow Laboratories, Inc., Rockville, Maryland. The cells were supplied as confluent monolayers at passage numbers 23 or 24 in Eagle's Minimum Essential Medium. This test system is specified by the Environmental Protection Agency's Level 1 Environmental Assessment Program.[1]

B. Medium and Cell Maintenance

The cells were maintained and treated in Basal Medium Eagle (BME) supplemented with 10% fetal bovine serum, 2mM L-glutamine, 100 units/ml penicillin, 100 μg/ml streptomycin, and 1.0 μg/ml amphotericin B (Fungizone). Subcultures were prepared twice weekly at a 1:2 split ratio using 0.25% trypsin. Cultures were discarded after the 35th subculture (passage).

C. Negative Controls

Three sets of negative control cultures, each in triplicate, were carried through the same experimental time period as the treated cells. One set was an untreated negative control consisting of cultures exposed only to BME culture medium. The other two sets were solvent controls containing 1% and 2% of the solvent exchanged DMSO blank, prepared as described below. The average viability, ATP content, and protein content of these solvent controls provided the reference points for determining the effects of different concentrations of the test material on the assay parameters. The 2% solvent control was the reference for the highest assayed concentration (20 μl/ml) and the 1% control was the reference for the remaining test concentrations.

2. MATERIALS (Continued)

D. Sample Preparation and Handling

The test material was received as a solution in 0.5 ml of methylene chloride and was stored at 4°C until solvent exchanged. The entire sample was exchanged into DMSO by first adding 1 ml DMSO and reducing the volume under a stream of nitrogen in a warm water bath (33°C). Then 0.5 ml DMSO was added and the solution evaporated again. This last process repeated once more, and the sample was diluted with DMSO to a final volume of 2.0 ml. This sample was stored at 4° C until use in the cytotoxicity assay. Since the original test sample represented 338 ft^3 of exhaust gas, the solvent exchanged sample corresponded to 169 ft^3 gas/ml or 4785.4 L gas/ml.

A solvent exchanged DMSO blank was also prepared by the above procedure, starting with 0.5 ml methylene chloride (same volume as the original test material).

3. EXPERIMENTAL DESIGN

A. Dose Selection

The solvent exchanged sample was tested from 20 μl/ml to 0.5 μl/ml in five dose steps. The 20 μl/ml treatment was the maximum dose because of the introduction of 2% DMSO in the growth medium. All other concentrations were obtained by 1:100 dilutions of the test sample and dilutions thereof (using DMSO) into the growth medium to give a 1% final concentration of solvent.

B. Culture Preparation

Stock cultures were subcultured into 100-mm plastic culture dishes 24 to 72 hours prior to use. This procedure provides a population of actively growing, sub-confluent cells to initiate the assay.

The cells were then suspended in BME culture medium by treatment with 0.25% trypsin for 3-5 minutes and the cell number determined by hemocytometer. A series of 25-cm^2 culture flasks were seeded with 20 x 10^4 cells and 4 ml culture medium per flask. The cultures were incubated overnight at 37°C in a humidified atmosphere containing 5% CO_2 to allow attachment of the cells and resumption of growth.

3. EXPERIMENTAL DESIGN (Continued)

C. Treatment

The medium was aspirated from the cultures and 4 ml of BME culture medium containing the test sample was applied. Three cultures were exposed to each test concentration and solvent exchanged DMSO blank. The flasks were then placed on a rocker platform in a 37°C incubator with a humidified atmosphere containing 5% CO_2. The flasks were slowly rocked for a 20 hour exposure period. Any color changes in the culture medium caused by the test material were noted and the pH determined in additional treated flasks.

D. Cell Viability Assay

At the end of the treatment period, the medium containing unattached cells was decanted into a centrifuge tube on ice. The cell monolayer was washed with 1 ml 0.05% trypsin/versene and this wash combined with the decanted media. The attached cells were then removed with 2 ml of 0.25% trypsin at 37°C and the suspended cells combined with the decantate. The cells from each flask were thereby resuspended in 7 ml volumes for subsequent analysis.

A 1.0 ml aliquot was removed for cell count and viability determination. The aliquot was combined with 0.2 ml or 0.5 ml of 0.4% trypan blue and counted by hemocytometer about 5 to 15 minutes later. Between 40 and 136 cells were counted per flask and the number of live (colorless) and dead (blue) cells were recorded.

E. ATP Assay

ATP was immediately analyzed by extraction of a 0.1 ml cell suspension sample with 0.9 ml of 90% DMSO. After 2 minutes at room temperature, 5.0 ml cold MOPS buffer (0.01 M morpholinopropane sulfonic acid) at pH 7.4 was added and the extract was vortexed and placed on ice. Aliquots of 10 ul were injected into a cuvette containing a luciferin-luciferase reaction mixture in a DuPont Model 760 Luminescence Biometer. The Biometer was calibrated with standard ATP solutions to provide a direct read-out of the ATP content. Each test sample was assayed three times to demonstrate consistent readings.

F. Lowry Protein Assay[2]

A 3.0 ml aliquot of the cell suspension was taken for protein analysis by the Lowry method. The aliquot was centrifuged at 365 x g for 10 minutes, the medium decanted, and the cell pellet resuspended in 3 ml PBS. After two additional centrifugation washes with PBS, the pellet was resuspended in 1.5 ml of PBS and frozen at -20°C or analyzed immediately. A 1.0 ml aliquot was used for the Lowry assay.

3. EXPERIMENTAL DESIGN (Continued)

At the end of the color development period, the tubes were centrifuged to remove any particulate test material prior to making absorbance readings at 750 nm. Lowry protein standard curves were constructed with bovine serum albumin for each assay.

4. REFERENCES

[1] IERL-RTP Procedures Manual: Level I. EPA-600/7-77-043, April 1977.

[2] Lowry, O.H., Rosebrough, N.J., Farr, A.L., and Randall, R.J.: Protein Measurement with Folin Phenol Reagent. J.Bio.Chem., 193:265-275, 1951.

ASSAY ACCEPTANCE CRITERIA

The assay will be considered acceptable for evaluation of the test results if the following criteria are met:

1. The passage level of the cells (number of subcultures) prior to use in the assay does not exceed 35.

2. The percent viability of the WI-38 cells used to initiate the assay is 95% or greater.

3. At least 1.5 x 10^5 cells are seeded per flask. The untreated negative control cultures must increase in cell number by at least 2-fold over the 20 hour treatment period.

4. A sufficient number of data points (for five test concentrations or less) are available to clearly locate the EC50 of the most sensitive test parameter within a toxicity region as defined under Evaluation Criteria.

5. The data points critical to the location of the EC50 for the most sensitive parameter are the averages of at least two treated cultures.

6. If all the test parameters yield EC50 values greater than 1000 μg/ml or 600 μl/ml, the plotted curves for any parameter will not exceed 120% of the negative control.

ASSAY EVALUATION CRITERIA

The EC50 value represents the concentration of test material that reduces an assay parameter to 50% of the negative control value. EC50 values are determined graphically by fitting a curve by eye through the data points associated with each test parameter plotted as a function of the logarithm of the applied concentration. Each point normally represents the average of three culture flasks for each treatment. Statistical analysis is unnecessary in most cases for evaluation.

The evaluation of the test material is based upon determinations of the EC50 values for five parameters: percent viability (ratio of viable cells to total cells x 100% for each treatment), viability index (ratio of viable cells for each treatment to viable cells in the negative control x 100%), cellular protein, total ATP content, and ATP per 10^6 cells. Except for the ATP content, these parameters are specified in the EPA Procedures Manual.[1] The ATP content will generally be a more sensitive parameter than ATP per 10^6 cells because any cell loss due to treatment will increase the latter parameter. ATP released into the growth medium by disrupted cells contributes to the ATP measurement.

The toxicity of the test material is evaluated as high, moderate, low or nondetectable according to the ranges of EC50 values defined in the following table. The actual concentration of extract at the EC50 is converted to the equivalent volume of exhaust gas per milliliter of culture medium prior to the evaluation. The assay parameter yielding the lowest EC50 will classify the test material.

Toxicity*	EC50 Values
High	EC50 < 10 L gas/ml
Moderate	EC50 range of 10-100 L gas/ml
Low	EC50 range of 100-1000 L gas/ml
Nondetectable	EC50 > 1000 L gas/ml

*Formulated by Litton Bionetics, Inc., under contract to the Environmental Protection Agency, Contract No. 68-02-2681.

APPENDIX F-2

MUTAGENICITY EVALUATION OF LOW NO_x XAD-2 EXTRACT IN THE AMES ASSAY

LBI ASSAY NO. 3985

LBI SAFETY NO. 3642

MUTAGENICITY EVALUATION OF

OIL FIRED BOILER NO. 1 SASS TRAIN XAD-2 EXTRACT (IN METHYLENE CHLORIDE)

IN THE AMES SALMONELLA/MICROSOME PLATE TEST

FINAL REPORT

SUBMITTED TO:

ACUREX CORPORATION
485 CLYDE AVENUE
MOUNTAIN VIEW, CA.
94042

SUBMITTED BY:

LITTON BIONETICS, INC.
5516 NICHOLSON LANE
KENSINGTON, MARYLAND 20795

LBI PROJECT NO. 20988

REPORT DATE: JUNE 1979

Litton BIONETICS

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I. SPONSOR: Acurex Corporation

II. MATERIAL (TEST COMPOUND): LBI ASSAY NUMBER 3985

A. Identification: Oil Fired Boiler No. 1 Sass Train XAD-2 Extract (in Methylene Chloride)*

B. Date Received: February 23, 1979

C. Physical Description: Clear, colorless liquid

III. TYPE OF ASSAY: Ames *Salmonella*/microsome Mutagenesis Assay

IV. PROTOCOL NUMBER: 401

V. STUDY DATES:

A. Initiation: May 18, 1979

B. Completion: June 8; 1979

VI. SUPERVISORY PERSONNEL:

A. Study Director: D.R. Jagannath, Ph.D.

B. Laboratory Supervisor: Sibyl Goode

VII. RESULTS:

The results of this assay are presented in Tables 1 and 2.

VIII. INTERPRETATION OF RESULTS:

The test compound was examined for mutagenic activity in a series of *in vitro* microbial assays employing *Salmonella* indicator organisms. The compound was tested directly and in the presence of liver microsomal enzyme preparations from Aroclor-induced rats.

The compound was tested at four concentrations according to the IERL-RTP procedures Manual: Level I (1977). The compound was tested for its mutagenic activity as well as for its toxicity at 0.01 mg, 0.1 mg, 1.0 mg and 10 mg per plate.

The toxicity results presented in Table 1 indicate that the test compound was not toxic at the doses employed in these studies both in the presence and absence of metabolic activation systems.

*See Sample Preparation and Handling

TA,

VIII. INTERPRETATION OF RESULTS (continued):

The mutagenicity results presented in Table 2 indicate that the test compound did not induce any genetic activity in any of the test organisms employed in these assays. The results of tests conducted on the test compound in the presence of a rat liver activation system were also negative. The test with TA-1537 was repeated in nonactivation and activation assays because of high solvent values in the initial test. The repeat tests were also negative.

IX. CONCLUSIONS:

The test compound, Oil Fired Boiler No. 1 Sass Train XAD-2 extract (in methylene chloride), did not demonstrate genetic activity or toxicity in any of the assays conducted in this evaluation and was considered as not mutagenic under these test conditions.

Submitted by:

Study Director

D.R. Jagannath 6.11.79

D.R. Jagannath, Ph.D. Date
Section Chief
Submammalian Genetics
Department of Genetics
and Cell Biology

Reviewed by:

(for) 6/11/79

David J. Brusick, Ph.D. Date
Director
Department of Genetics
and Cell Biology

Litton BIONETICS

V. RESULTS

TABLE 1

A. NAME OR CODE DESIGNATION OF THE TEST COMPOUND: OIL FIRED BOILER NOI SASS TRAIN XAD-2 EXTRACT (IN METHYLENE CHLORIDE)
B. SOLVENT: DMSO
C. TEST INITIATION DATES: 05/18/79 05/30/79
D. TEST COMPLETION DATE:06/08/79
F. S-9 LOT#: CR024
NOTE: CONCENTRATIONS ARE GIVEN IN MILLIGRAMS (MG) PER PLATE

TEST	SPECIES	TISSUE	INDICATOR ORGANISMS (POPULATION/10^6)							
			TA-1535		TA-1537		TA-98		TA-100	
			1	2	1	2	1	2	1	2
NONACTIVATION										
SOLVENT CONTROL	---	---	393		264	191	298		1853	
POSITIVE CONTROL**	---	---	315		159	91	298		1649	
TEST COMPOUND										
0.010000 MG	---	---	396		266	204	293		1880	
0.100000 MG	---	---	342		271	160	321		896	
1.100000 MG	---	---	357		265	173	344		842	
10.000000 MG	---	---	325		300	170	342		360	
ACTIVATION										
SOLVENT CONTROL	RAT	LIVER	378		311	223	351		400	
POSITIVE CONTROL***	RAT	LIVER	551		191	101	312		331	
TEST COMPOUND										
0.010000 MG	RAT	LIVER	361		281	132	345		374	
0.100000 MG	RAT	LIVER	348		293	150	408		402	
1.000000 MG	RAT	LIVER	341		300	133	368		343	
10.000000 MG	RAT	LIVER	373		280	177	356		304	

**

TA-1535	SODIUM AZIDE	1 UG/PLATE
TA-1537	9-AMINOACRIDINE	50 UG/PLATE
TA-98	2-NITROFLUORENE	10 UG/PLATE
TA-100	SODIUM AZIDE	1 UG/PLATE
SOLVENT	50 UL/PLATE	

***

TA-1535	2-ANTHRAMINE	2.5 UG/PLATE
TA-1537	2-ANTHRAMINE	2.5 UG/PLATE
TA-98	2-ANTHRAMINE	2.5 UG/PLATE
TA-100	2-ANTHRAMINE	2.5 UG/PLATE

TABLE 2

V. RESULTS

A. NAME OR CODE DESIGNATION OF THE TEST COMPOUND: OIL FIRED BOILER NOT SASS TRAIN XAD-2 EXTRACT (IN METHYLENE CHLORIDE)
B. SOLVENT: DMSO
C. TEST INITIATION DATES: 05/18/79
D. TEST COMPLETION DATE: 06/08/79
E. S-9 LOT#:
NOTE: CONCENTRATIONS ARE GIVEN IN MILLIGRAMS (MG) PER PLATE

TEST	SPECIES	TISSUE	INDICATOR ORGANISMS (REVERTANTS/PLATE)							
			TA-1535		TA-1537		TA-98		TA-100	
			1	2	1	2	1	2	1	2
NONACTIVATION										
SOLVENT CONTROL	---	---	19		45	12	34		124	
POSITIVE CONTROL**	---	---	1023		352	265	1384		1923	
TEST COMPOUND										
0.010000 MG	---	---	13		30	4	42		98	
0.100000 MG	---	---	8		33	7	52		93	
1.000000 MG	---	---	15		38	5	39		94	
10.000000 MG	---	---	16		50	17	48		116	
ACTIVATION										
SOLVENT CONTROL	RAT	LIVER	16		52	17	65		112	
POSITIVE CONTROL***	RAT	LIVER	414		272	110	2926		2046	
TEST COMPOUND										
0.010000 MG	RAT	LIVER	8		46	9	46		80	
0.100000 MG	RAT	LIVER	7		53	6	53		110	
1.000000 MG	RAT	LIVER	17		37	5	57		108	
10.000000 MG	RAT	LIVER	20		41	29	48		103	

**

TA-1535	SODIUM AZIDE	1 UG/PLATE
TA-1537	9-AMINOACRIDINE	50 UG/PLATE
TA-98	2-NITROFLUORENE	10 UG/PLATE
TA-100	SODIUM AZIDE	1 UG/PLATE
SOLVENT	50 UL/PLATE	

***

TA-1535	2-ANTHRAMINE	2.5 UG/PLATE
TA-1537	2-ANTHRAMINE	2.5 UG/PLATE
TA-98	2-ANTHRAMINE	2.5 UG/PLATE
TA-100	2-ANTHRAMINE	2.5 UG/PLATE

SAMPLE PREPARATION AND HANDLING

The test material was received as a solution in 0.5 ml of methylene chloride and was stored at 40°C until solvent exchanged. The entire sample was exchanged into DMSO by first adding 2 ml DMSO and reducing the volume to 2 ml under a stream of nitrogen in a warm water bath (33°C). Then 0.5 ml DMSO was added and the solution evaporated again to 2 ml. This last process was repeated once more, leaving the sample in a final volume of 2.0 ml. This sample was stored at 4°C until use in the cytotoxicity assay. Since the original test sample represented 338 ^{3}ft of exhaust gas, the solvent exchanged sample corresponded to 169 ft^3 gas/ml or 4785.4 L gas/ml.

A solvent exchanged DMSO blank was also prepared by the above procedure, starting with 0.5 ml methylene chloride (same volume as the original test material). Since the test material did not exhibit any mutagenic or toxic effect on the indicator organism in these assays, solvent exchanged DMSO blank was not tested separately.

PROTOCOL NO. 401

AMES SALMONELLA/MICROSOME PLATE ASSAY

1. OBJECTIVE

The objective of this study is to evaluate a test material for mutagenic activity in a bacterial assay with and without a mammalian S9 activation system.

2. RATIONALE

The Salmonella typhimurium strains used at LBI are all histidine auxotrophs by virtue of mutations in the histidine operon. When these histidine-dependent cells are grown in a minimal media petri plate containing a trace of histidine, only those cells that revert to histidine independence (his+) are able to form colonies. The trace amount of histidine allows all the plated bacteria to undergo a few divisions; this growth is essential for mutagenesis to occur. The his+ revertants are easily scored as colonies against the slight background growth. The spontaneous mutation frequency of each strain is relatively constant; but when a mutagen is added to the agar, the mutation frequency is increased 2- to 100-fold. Cells which grow to form colonies on the minimal media petri plates are therefore assumed to have reverted, either spontaneously or by the action of a test substance to his+ genotype.

3. MATERIALS

A. Indicator Microorganisms

The Salmonella typhimurium strains used in this assay were obtained from Dr. Bruce Ames, University of California at Berkeley.[1-5] The following 4 strains are used.

Strain Designation	Gene Affected	Additional Mutations			Mutation Type Detected
		Repair	LPS	R Factor	
TA-1535	his G	Δ uvr B	rfa	-	Base-pair substitution
TA-1537	his C	Δ uvr B	rfa	-	Frameshift
TA-98	his D	Δ uvr B	rfa	pKM101	Frameshift
TA-100	his G	Δ uvr B	rfa	pKM101	Base-pair substitution

All the above strains have mutation in the histidine operon, mutation (*rfa*$^-$) that leads to defective lipopolysaccharide coat, a deletion that covers genes involved in the synthesis of vitamin biotin (*bio*$^-$) and in the repair of ultraviolet (uv)- induced DNA damage (*uvrB*$^-$). The *rfa*$^-$ mutation makes the strains more permeable to many large molecules. The *uvrB*$^-$ mutation decreases repair of some types of chemically or physically damaged DNA and thereby enhances the strain's sensitivity to some mutagenic agents. The resistant transfer factor plasmid (R factor) pKM101, in TA-98 and TA-100 is believed to cause an increase in error-prone DNA repair that leads to many more mutations for a given dose of most mutagens[5]. In addition, plasmid pKM101 confers resistance to the antibiotic ampicillin, which is a convenient marker to detect the presence of plasmid in the cells.

All indicator strains are kept at 4°C on minimal medium plates supplemented with a trace of biotin and an excess of histidine. The plates with plasmid-carrying strains contain in addition ampicillin (25 μg/ml), to ensure stable maintenance of plasmid pKM101. New stock culture plates are made every two months from the frozen master cultures or from single colony reisolates that were checked for their genotypic characteristics (*his*, *rfa*, *uvrB*, *bio*) and for the presence of plasmid. For each experiment, an inoculum from the stock culture plates is grown overnight at 37°C in nutrient broth (Oxoid CM67) and used.

B. Media

The bacterial strains were cultured in Oxoid Media #2 (nutrient Broth). The selective medium was Vogel Bonner Medium E with 2% glucose.[7] The overlay agar will consist of 0.6% purified agar with 0.5 mM histidine, 0.05 mM biotin and 0.1M NaCl according to the methods of Ames *et al*.[6]

C. Activation System

(1) S9 Homogenate

A 9,000 x *g* supernatant prepared from Sprague-Dawley adult male rat liver induced by Aroclor 1254 (described by Ames *et al*.[6]) was purchased from Bionetics Laboratory Products, Litton Bionetics, Inc. and used in this assay.

(2) S9 Mix

Components	Concentration per Milliliter S9 Mix
NADP (sodium salt)	4 μmoles
D-glucose-6-phosphate	5 μmoles
$MgCl_2$	8 μmoles
KCl	33 μmoles
Sodium phosphate buffer pH 7.4	100 μumoles
Organ homogenate from rat liver (S9 fraction)	100 μliters

4. EXPERIMENTAL DESIGN

A. Dosage Selection

The tests are run at four concentrations according to the EPA Level I Manual. The recommended doses are 0.01, 0.1, 1.0 and 10 mg per plate. Both mutagenicity testing and toxicity testing are performed using these four doses.

B. Mutagenicity Testing

The procedure used is based on the paper published by Ames *et al*.[6] and is performed as follows:

(1) Nonactivation Assay

To a Sterile 13 x 100 mm test tube placed in a 43°C water bath the following is added in order:

(a) 2.00 ml of 0.6% agar containing 0.05 mM histidine and 0.5 mM biotin.

(b) 0.05 ml of a solution of the test chemical to give approximate dose.

(c) 0.1 ml - 0.2 ml of indicator organism/s.

(d) 0.50 ml of 0.01M phosphate buffer, pH 7.4.

This mixture is swirled gently and then poured into minimal agar plates (see 3B, Media). After the top agar has set, the plates are incubated at 37 C°for approximately 2 days. The number of *his*+ revertant colonies growing in the plates is counted and recorded.

(2) Activation Assay

The activation assay is run concurrently with the nonactivation assay. The only difference is the addition of 0.5 ml of S9 mix (see 3C:2, Activation System) to the tubes in place of 0.5 ml of phosphate buffer which is added in nonactivation assays. All other details are similar to the procedure for nonactivation assays.

A detailed flow diagram for the plate incorporation assay is provided in Figure 1.

C. Control Compounds

A negative control consisting of the solvent used for the test material is performed in all cases. For negative controls, step 'b' of Nonactivation Assays is replaced by 0.05 ml of the solvent. The negative controls are employed for each indicator strain and is performed in the absence and presence of S9 mix. The solvent used to prepare the stock solution of the test material is given in the Results section of this report. All dilutions of the test material made using this solvent.

Specific positive control compounds known to revert each strain are also used in the assays. The concentrations and specificities of these compounds to specific strains are given in the following table.

Assay	Chemical	Solvent	Concentration per Plate (g)	*Salmonella* Strains
Nonactivation	Sodium azide	Water	1	TA-1535, TA-100
	2-Nitrofluorene (NF)	Dimethyl-sulfoxide	10	TA-98
	9-aminoacridine (9AA)	Ethanol	50	TA-1537
Activation	2-anthramine (ANTH)	Dimethyl-sulfoxide	2.5	For all strains

D. Toxicity Test

To a sterile 13 x 100 mm test tube placed in a 43°C water bath the following is added in order:

(a) 2.0 ml of 0.6% agar containing 0.05 mM histidine and 0.05 mM biotin.

(b) 0.05 ml of a solution of the test chemical to give approximate dose.

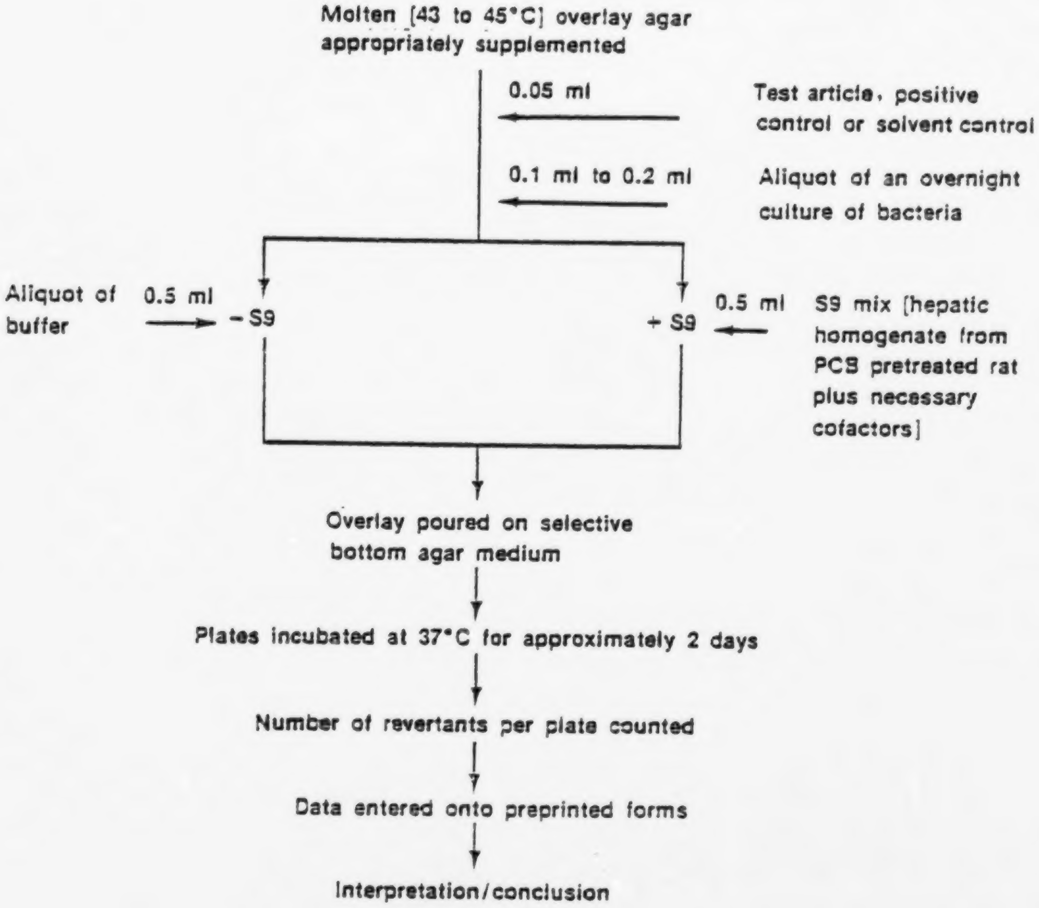
(c) 0.1-0.2 ml of indicator cells (approximately 200 cells from an overnight culture appropriately dilute).

(d) 0.50 ml of 0.01M phosphate buffer, pH 7.4 (for nonactivation assays) or S9 mix (see 3c:2) (for activation assays).

This mixture is swirled gently and then poured over the surface of nutrient agar plates. After the top agar has set, the plates are incubated at 37°C for 2 days. The number of colonies growing on the plates is counted and recorded.

FIGURE 1

REVERSE MUTATION ASSAY
[Agar Incorporation Method]


Molten [43 to 45°C] overlay agar appropriately supplemented
0.05 ml
Test article, positive control or solvent control
0.1 ml to 0.2 ml
Aliquot of an overnight culture of bacteria
Aliquot of buffer
0.5 ml
−S9
+S9
0.5 ml
S9 mix [hepatic homogenate from PCB pretreated rat plus necessary cofactors]
Overlay poured on selective bottom agar medium
Plates incubated at 37°C for approximately 2 days
Number of revertants per plate counted
Data entered onto preprinted forms
Interpretation/conclusion

5. EVALUATION CRITERIA

Statistical methods are not currently used, and evaluation is based on the criteria included in this protocol.

Plate test data consists of direct revertant colony counts obtained from a set of selective agar plates seeded with populations of mutant cells suspended in a semisolid overlay. Because the test material and the cells are incubated in the overlay for approximately 2 days and a few cell divisions occur during the incubation period, the test is semiquantitative in nature. Although these features of the assay reduce the quantitation of results, they provide certain advantages not contained in a quantitative suspension test:

- The small number of cell divisions permits potential mutagens to act on replication DNA, which is often more sensitive than nonreplicating DNA.
- The combined incubation of the test article and the cells in the overlay permits constant exposure of the indicator cells for approximately 2 days.

A. Surviving Populations

Plate test procedures do not permit exact quantitation of the number of cells surviving chemical treatment. At low concentrations of the test material, the surviving population on the treatment plates is essentially the same as that on the negative control plate. At high concentrations, the surviving population is usually reduced by some fraction. Our protocol will normally employ several doses ranging over two or three log concentrations, the highest of these doses being selected to show slight toxicity as determined by subjective criteria.

B. Dose-Response Phenomena

The demonstration of dose-related increases in mutant counts is an important criterion in establishing mutagenicity. A factor that might modify dose-response results for a mutagen would be the selection of doses that are too low (usually mutagenicity and toxicity are related). If the highest dose is far lower than a toxic concentration, no increases may be observed over the dose range selected. Conversely, if the lowest dose employed is highly cytotoxic, the test material may kill any mutants that are induced, and the test material will not appear to be mutagenic.

C. Control Tests

Positive and negative control assays will be conducted with each experiment and will consist of direct-acting mutagens for nonactivation assays and mutagens that require metabolic biotransformation in activation assays. Negative controls will consist of the test material solvent in the overlay agar together with the other essential components. The negative control plate for each strain will give a reference point to which the test data will be compared. The positive control assay will be conducted to demonstrate that the test systems are functional with known mutagens.

D. Evaluation Criteria for Ames Assay

Because the procedures to be used to evaluate the mutagenicity of the test material are semiquantitative, the criteria to be used to determine positive effects are inherently subjective and are based primarily on a historical data base. Most data sets will be evaluated using the following criteria.

(1) Strains TA-1535 and TA-1537

If the solvent control value is within the normal range, a test material that produces a positive dose response over three concentrations with the highest increase equal to three times the solvent control value will be considered to be mutagenic.

(2) Strains TA-98 and TA-100

If the solvent control value is within the normal range, a test material that produces a positive dose response over three concentrations with the highest increase equal to twice the solvent control value for TA-98 and TA-100 will be considered to be mutagenic.

(3) Pattern

Because TA-1535 and TA-100 are both derived from the same parental strain (G-46) and because TA-1538 and TA-98 are both derived from the same parental strain (D3052), to some extent there is a built-in redundancy in the microbial assay. In general, the two strains of a set respond to the same mutagen and such a pattern is sought. Generally, if a strain responds to a mutagen in nonactivation tests, it will do so in activation tests.

(4) Reproducibility

If a test material produces a response in a single test that cannot be reproduced in additional runs, the initial positive test data lose significance.

The preceding criteria are not absolute, and other extenuating factors may enter into a final evaluation decision. However, these criteria will be applied to the majority of situations and are presented to aid those individuals not familiar with this procedure. As the data base is increased, the criteria for evaluation can be more firmly established.

E. Relation between Mutagenicity and Carcinogenicity

It must be emphasized that the Ames *Salmonella*/Microsome Plate Assay is not a definitive test for chemical carcinogens. It is recognized, however, that correlative and functional relations have been demonstrated between these two endpoints. The results of comparative tests on 300 chemicals by McCann et al.[1] show an extremely good correlation between results of microbial mutagenesis tests and *in vivo* rodent carcinogenesis assays.

All evaluations and interpretation of the data to be presented in the final report will be based only on the demonstration, or lack, of mutagenic activity.

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